Atomic Energy
Control Board

P.O. Box 1046
Ottawa, Canada
K1P 5S9

Commission de contrôle
de l'énergie atomique

C.P. 1046
Ottawa, Canada
K1P 5S9

INFO-0265

NEOTECTONICS IN THE MARITIME PROVINCES

by

G.L. Martin
Language Unlimited

A research report prepared for the
Atomic Energy Control Board
Ottawa, Canada

March 1988

Canada

Research report

NEOTECTONICS IN THE MARITIME PROVINCES

A literature compilation prepared by Gwen L. Martin, Language Unlimited, under contract to the Atomic Energy Control Board.

ABSTRACT

Seismic risk assessment in the Maritime Provinces requires input from not just historical, but also geological sources. A detailed search through published and unpublished geological literature reveals many examples – some probable, some possible – of neotectonic movement in the area. Examples range in tectonic significance from those that reflect exaggerated local imbalance to those that signify deep-seated stress.

Evidence for neotectonism in the Maritimes is multidisciplined. It includes deformation in bedrock and quaternary deposits, and regional warping. Recent movement also is indicated by changes in relative sea level, in situ stress fields and geodetic fluctuations. Finally, and most unequivocally, neotectonism in the Maritime Provinces is manifested as the seismic events that have sporadically affected the area throughout its recent geological history, and continue up to the present day.

RÉSUMÉ

L'évaluation du risque de séisme dans les provinces maritimes nécessite l'apport de sources non seulement historiques, mais géologiques. Une recherche détaillée de la documentation publiée et inédite en géologie a révélé plusieurs exemples probables ou possibles de mouvement néotectonique dans la région. L'importance tectonique des exemples varie entre l'exagération du déséquilibre local et les contraintes en profondeur.

Les preuves de néotectonisme dans les Maritimes touches à plusieurs disciplines. Elles comprennent des déformations de la roche de fond et des dépôts quaternaires, ainsi que le plissement régional. Les modifications récentes relèvent surtout du changement du niveau relatif de la mer, des champs de contrainte sur place et des fluctuations géodésiques. En dernier lieu et de manière très inéquivoque, le néotectonisme se manifeste dans les provinces maritimes par les différents séismes qui ont ébranlé sporadiquement la région tout au long de son histoire géologique récente jusqu'à nos jours.

DISCLAIMER

The Atomic Energy Control Board is not responsible for the accuracy of the statements made or opinions expressed in this publication. Neither the Board nor the author assumes liability with respect to any damage or loss incurred as a result of the use made of the information contained in this publication.

PREFACE

Why A Report On Neotectonism?

Seismic risk assessment in eastern Canada today is limited. It relies solely on the evaluation of historic and current seismic data. Historical data in the Maritime Provinces reaches back some 350 years - hardly long enough to forecast any geological process, let alone one as sporatic as an earthquake.

Even civilizations much older and more seismologically experienced than our own have been caught offguard. China has been recording seismic events for over 2000 years; yet the tragic 1976 Tangshan earthquake that killed several thousand people was totally unexpected.

We must extend our knowledge of Maritimes seismicity much further back in time to seriously attempt seismic prediction. We must examine, not just the historical, but also the geological record. In particular, we require more information on **neotectonism** in the Maritime Provinces.

Neotectonism Defined

'Neotectonism' generally refers to recent movements of the earth's crust and/or its overlying sediments during the last ten million years or so. The definition below is paraphrased from Mörner (1987):

> Neotectonics defines any earth movement or deformation of the geodetic reference level, plus its mechanisms and geological origin, however old. It includes movements from the present back to about 10 million years ago. [The time frame covered by this report encompasses the entire Cenozoic.]
>
> Neotectonics deals not just with vertical and horizontal crustal movements, and their deep seated sources, but also with deformation of the oceanic and continental geoid, including gravity phenomena.

Neotectonic features may be divided into those unequivocally related to regional tectonism, and those for which interpretation is less certain. Erosional unloading phenomena, apparent ice contact deposits and frost heaves, mine subsidence, karst solutions and gravity slumps are among the so-called 'superficial' neotectonic features. These features rarely (albeit occasionally) result from deep seated tectonism. Yet they can, in some cases, delineate seismically significant structural weaknesses in the underlying rocks.

Scope Of This Report

The present report is essentially a database: a comprehensive compilation of published and unpublished documentation of neotectonism in Nova Scotia and New Brunswick, with selected entries from Maine.

By no means every entry describes a tectonically-caused neotectonic feature. However, we simply do not know enough yet to dismiss, say, all landslides as gravity slumping, or all karst topography as purely solution weathering. Small earthquakes can trigger landslides. Minute movement along ancient faults can initiate mass subsidence in karst terrane. And so on.

Only detailed field work will sort out, as it were, the deep seated tectonic wheat from the superficial chaff. Ultimately, data from this report and subsequent field studies can be synthesized into seismotectonic and seismic risk maps.

TABLE OF CONTENTS

PART I. READING NEOTECTONISM:

Geological, Geomorphological and Marine Geological Evidence for Neotectonism in the Maritime Provinces

Abstract ii
Preface iv

Chapter I: RECENT FAULTING AND DEFORMATION OF BEDROCK

A. Recent thrust faulting 1
B. Joint displacement 7
C. Pop-ups, buckles and rockbursts 9
D. Regional crustal warping 12

Chapter II: FAULTING AND DEFORMATION OF GLACIAL AND POSTGLACIAL DEPOSITS

A. Faults and slumps 13
B. Injection features 22
C. Offset wavecut benches and strandlines 24

Chapter III: MASS SUBSIDENCE

A. Karsts and sinkholes 26
B. Kettles 29
C. Mine subsidence 30
D. Landslides, rockslides and other subsidence 31

Chapter IV: CHANGES OF SEA LEVEL 38

A. Sea level changes and neotectonism 39

B. Evidence for crustal subsidence and uplift 39

Chapter V: OFFSHORE GEOLOGY 40

A. Submarine slumps and slides 41

B. Recent faulting and regional uplift/subsidence ... 48

C. Pockmarks 52

PART II. MEASURING NEOTECTONISM:

Direct and Indirect Measurements of Neotectonism in the Maritime Provinces

Chapter VI: DIRECT MEASUREMENTS OF NEOTECTONISM

A. Geodetic surveys 53
B. Tidal gauge data 56
C. Gravity and tiltmeter observations 57

Chapter VII: INDIRECT MEASUREMENTS OF NEOTECTONISM

A. In situ measurements 60
B. Microstructures 63

PART III. EXPERIENCING NEOTECTONISM:

Historical and Current Seismicity in the Maritime Provinces

Chapter VIII: HISTORICAL SEISMICITY

A. Compilations of historical seismic events 64
B. Seismotectonics 66

Chapter IX: CURRENT SEISMICITY

A. Regional seismic detection 69
B. Focal plane mechanisms 71

Chapter X: MISCELLANEOUS INDICATORS OF NEOTECTONISM

A. Groundwater phenomena 75
B. Tsunamis 77
C. Sound phenomena 78
D. Road cracks 78
E. Warm spots 79

BIBLIOGRAPHY 80

ACKNOWLEDGEMENTS 106

APPENDIX A 107

Selected unannotated references
concerning the 1982 Miramichi
earthquakes and related aftershocks.

APPENDIX B 109

Selected references describing
post-Triassic bedrock faulting
of indeterminate upper age.

APPENDIX C 112

A reading list to aid in
distinguishing neotectonic
features in the field.

APPENDIX D 114

Contact addresses for references
cited as 'pers. comm.' or 'unpublished'.

PART I. READING NEOTECTONISM: Geological, Marine Geological and Geomorphological Evidence for Neotectonism in the Maritime Provinces

CHAPTER I: RECENT FAULTING AND DEFORMATION OF BEDROCK

A. RECENT THRUST FAULTING

New Brunswick

I.A.1
J. Adams (research files)

Faults that offset glacial striae occur in several greywacke outcrops beside the Mactaquac dam near Fredericton, New Brunswick. Vertical displacement is 2 cm to 3 cm, and is subparallel to the main cleavage. Throws on most offsets are to the west-northwest, although some are in the opposite direction.

The report cites two possible explanations for the faulting: frost heaving or tectonic movements.

I.A.2
M. Lamothe (unpublished field observations)

Lamothe reports having seen 'hundreds' of offset glacial striae in Ordovician slates between Grand Falls and Edmundston, and several displaced striae in the St. Jacques area in northern New Brunswick. Rampton et al. (1984) also mention minor displacement of striae in slate near Edmundston.

I.A.3
Matthew 1894a

Matthew describes two sets of postglacial faults from five sites within the city of Saint John, New Brunswick: along a hillside south of 'The Valley', on City Road near the City Hospital, on a hillside east of Charles Street, on Rock Street and at the northeast corner of the Church of England cemetary.

The faults displace glacial striae, which cut across steeply dipping slates. The primary set of faults strikes northeast-southwest, while a secondary diagonal set strikes north-south and east-west. The faults are reverse and dip from 70° to 90° southeast.

All but two faults are upthrown to the southeast. Throws range from 0.25 inches to 5 inches. According to Matthew, "at almost every place in the city and east and west of it, where glaciated ledges of the [St. John Group] slates could be observed, some displacement was seen, though often very slight" (p. 503).

I.A.4
Matthew 1894b

This more detailed version of Matthew 1894a gives displacements of individual faults. The City Road locality shows 9 faults with a total offset of 10 inches over an 11.5-foot outcrop. The Rock Street locality shows 62 faults with a total offset of 68 inches over 156 feet.

Two additional postglacial faulting sites are mentioned: Peel Street and Pond Street.

Matthew ascribes the postglacial faults to tectonic thrusting from the southeast. He also cites two objects (a boulder and a lance head) that had been broken, offset and re-cemented as further evidence of recent earth movement. (Frost action seems a more likely explanation for these latter features).

I.A.5
M. Rappol (pers. comm.)

Offset glacial striae have been observed northwest of St. Jacques, New Brunswick, on a flat-topped ridge of slate that trends 045°. The fracture displacing the striae strikes nearly parallel to the ridge. Vertical displacement reaches a maximum of 7 cm to 8 cm.

I.A.6
Seaman (unpublished field observations)

In 1985, faults trending east-west were seen to displace glacial striae by about 5 cm. The outcrop, now buried, lies at UTM 434 627 in Fundy National Park, New Brunswick.

I.A.7
Thibault and Seaman (unpublished field observations)

Two sets of vertical faults offsetting glacial striae have been noted 3.5 km east of Edmundston. The outcrop, which lies at UTM 545 469, is of steeply dipping Lower Devonian slates.

Faults trending 50° and dipping 73° south offset the striae by throws of up to 23 mm, with 0 mm to 2 mm lateral displacement. Faults oriented at 125° and dipping 41° east offset the striae by throws of up to 28 mm, with no lateral displacement.

I.A.8
C. Van Staal (pers. comm.)

Offset glacial striations occur in iron formation in sericite schist near the Austin Brook No. 6 Mine, northern New Brunswick. Van Staal mapped the outcrop in 1981 and saw no offset striae. A year later - a few months after the 1982 Miramichi earthquakes - he revisited the site and found that the striae had become offset.

Nova Scotia

I.A.9
Calder 1984

A thrust fault that postdates all other observed faults occurs in the Novaco open pit coal mine at Springhill. The fault is closely related to bedding plane movement, in that it resulted from prior stratal slip. Modern stratal slip faulting also was recorded in the roof strata of the No. 2 Mine at Springhill, indicating that the coalfield retains a residual lateral stress component.

A definite age has not been assigned to the thrust faults. However, no discernable deformation could be seen in till overlying the Novaco Fault (J. Calder, pers. comm.).

I.A.10
Goldthwait 1924

Offset striae are noted in several Nova Scotia locales. At Caledonia Corner, a fault scarp on one outcrop trends 51°, and has displaced striae by throws of five, seven and eight inches. At each throw, the northwest block is uplifted.

A few examples of throws ranging from one to two inches can be observed in slate beside Prince of Wales tower in Point Pleasant Park and on Fairy Rocks at Lake Kejimkujik.

I.A.11
Grant 1980b

Postglacial faulting in slate at Cape Cove near Salmon River, southwest Nova Scotia, is evidenced by offset glacial striae. The vertical throws average 5 cm on the more than twenty dislocations that occur over a width of 3 m. Displacement is along the cleavage planes, and up to the south. Grant (1987) describes the total displacement as being of at least one metre.

Movement is tentatively ascribed to postglacial rebound, during which stresses became concentrated along incompetent slate zones rather than causing broad regional warping.

I.A.12
R. Stea (pers. comm.)

Offset glacial striations in central Nova Scotia have been documented from the following locations. All show a vertical displacement.

Latitude	Longitude	Lithology	Azimuth	Displacement
61.54174	45.54152	silt	025°	2 cm
61.55853	45.44087	conglomerate	110°	2-4 cm
62.67738	45.39727	silt	090°	5 cm
62.54062	45.35302	slate	?	1 cm
?	?	conglomerate	080°	2 cm

I.A.13
J. Oliver (notes in J. Adams research files, 1979)

Oliver visited the three sites mentioned by Goldthwait (see I.A.10).

He found no clear examples of postglacial faults at Fairy Rocks. However, an outcrop (not the original one) near Caledonia Corners revealed one clear postglacial fault in slate. The fault displaced striae vertically by 0.75 inches, south side up, and trended 070°.

Rocks showing the offset striae at Point Pleasant Park were not, in Oliver's estimation, particularly 'slatey'. Total offset was several inches along faults that trended east-west, south side down. Sinuous banding in the rock was discontinuous across the faults, indicating substantial preglacial as well as postglacial movement.

Maine

I.A.14
Koons (in press)

Fifty-six accounts of postglacial bedrock faulting in Maine are documented. Some are detailed, and are summarized below. The remaining entries give location (latitude, longitude, nearest town and quadrangle), formation name and reference. References give no information on the fault strike or displacement sense.

Most of the 56 postglacial faults show small displacements in the range of 0.5 cm to 1.5 cm. Fault planes are usually vertical or near vertical. Movement is generally dip slip, although some strike-slip component may be present.

All reported occurrences of postglacial faults are in fissile rocks. In all but one instance, the fault planes are parallel to the dominant structure, that being bedding, slatey cleavage or schistosity.

Interestingly, 72 per cent of the faults fall on or close to the dominant structural 'grain' of Maine, which trends 45° northeast. Where there is a local departure, as near a fold nose, the fault parallels the local structure.

Koons concludes that the observed postglacial faulting results mainly from frost heaving or glaciotectonic effects in rocks broken by bedding, schistosity and sheeting. Deep seated tectonism may have been involved, but there is no evidence to support the supposition.

1. Wadleigh Head:
Glacial striations are offset along a fracture striking 52° in the Kittery Formation. The northwest block is raised 0.6 cm to 1.3 cm. Fracture dips 68° to 72° northwest. Striations are offset about 0.3 cm in the same sense along a second fracture dipping 63° southeast. Believed to result from frost heaving.

2. Hopkins Island:
Glacial striations are offset along a north-trending fracture dipping 78° west in Cape Elizabeth Formation. A second similar fracture is located about 2 m east, parallel to the first. Believed to result from frost heaving.

3. Amity Quadrangle:
Glacial striations are offset along a fracture trending 70° in an unnamed sedimentary rock. Excavation shows the apparent fault resulted from glacial plucking along the joint.

4. Moxie Dam:
Glacial striations are offset up to 3 cm along vertical fractures trending 64° in Carrabassett Formation. Faults are up to 16 m long. Sense of displacement is opposite on two major fractures. Believed to result from frost heaving.

5. Near Spruce Pond:
Three closely spaced thrust faults trending 10° and dipping 40° northwest offset glacial striations in the Smalls Falls Formation. Southeast side is up. Believed to result from frost heaving.

(Boone (1980) locates this outcrop 1.2 km southeast of Spruce Pond. He reports that bedrock offset is about 15 cm on each fault with no evidence of a strike-slip component.)

6. Fox Brook:
Glacial striations are offset along southeast-trending bedding plane fractures in the Seboomook Formation, and along a cross-fracture trending 40° between bedding planes. Northwest side is raised. Believed to result from frost heaving.

7. Mile 232.5, Route I-95:
Glacial striations are offset along bedding plane fractures striking 40° and dipping 85° northwest, and along cross-fractures. Exposure is a roadcut created by recent construction. Offsets apparently postdate construction. Believed to result from frost heaving.

I.A.15
Newberg 1983

Newberg describes an outcrop that shows possible evidence of recent tectonism. It lies in the Piscataquis River below the dam at Howland in Maine. There, siltstone beds and a late fracture cleavage are offset by a fault that extends into a breccia zone up to 8 cm wide. The fault trace trends 320°.

I.A.16
Prowell 1983

A postglacial fault is recorded on the northwest side of Moxie Dam, 5 miles east of The Forks, Maine. The vertical fault strikes 65° and offsets basement rocks of the Lower Devonian Carrabassett Formation. Displacement reaches up to 1.5 inches with the northwest side downthrown. The marker horizon is represented by glacial striations on slate.

(This appears to refer to the same outcrop mentioned in I.A.14.)

I.A.17
Thompson 1981

Examination of landforms, surficial deposits and over two hundred bedrock outcrops in Maine near the Norumbega Fault Zone revealed only six localities of definite postglacial faulting. All fault displacements involve small (1.5 mm to 30 mm) offsets of glacially striated bedrock. Most, but not all, offsets occur along northeast-trending bedding plane faults.

Frost heaving is proposed as the primary cause of the observed postglacial faulting. Regional tectonic stresses, however, are an alternate possibility, in which case faulting may be related to seismic activity that has been recorded in the Norumbega Fault area.

I.A.18
Westerman 1983

Postglacial faulting was observed in the Sangerville Formation on a glacially striated outcrop south of Boyd Lake, Maine. The fault trends 55° and vertically offsets striations along strike for about 20 m. Displacement was about 7 mm, south side down. No evidence exists to suggest that offset is due to frost heaving.

Outcrops on roadcuts in the Carrabassett Formation along Route 15 also show postglacial faulting. Striations are offset, south side down, by five cleavage surfaces trending 45°. The faults may have been caused by blasting and/or frost heaving.

B. JOINT DISPLACEMENT

New Brunswick

I.B.1
Adams (unpublished report)

In August 1984 a 1240-m trench was dug across an outcrop thought to encompass the fault plane ruptured during the 1982 Miramichi mainshock in New Brunswick. Trenching uncovered no such fault plane. However, it revealed fresh bedrock fractures. The four main fracture zones are described below.

Fractures at site m1423 trended approximately east-west and occurred along pre-existing joints in Ordovician granite.

Site m1133 showed three open cracks in diorite. Each crack, trend 030°, was about 1 mm to 2 mm wide. Some vertical movement was observed. The cracks appeared along pre-existing joints.

Site m1144 showed five open cracks, trend 030°, and 1 mm to 7 mm wide. One block about 150 mm wide was elevated 100 mm higher than the adjacent glaciated surface. These open cracks also appeared along pre-existing joints.

At site m1000, most of the fresh fractures followed the dominant joint sets that trend about 030° and 100°. The fractures trending 030° parallel one P-nodal fault plane (Adams et al. 1984). Other fractures appear unrelated to pre-existing joints.

Although the fractures did not offset glacial striae, their edges were very fresh and angular. Some were tightly filled with glacial till, while others were completely open. This suggests two generations of crack opening: one dating from glacial times, and the other, presumably, dating from the 1982 mainshock.

The four fractures zones indicate tensional stress. This contrasts with the buckle and thrust joint features observed in 1983 (see I.C.1) which apparently resulted from high horizontal compressive stress.

I.B.2
J. Adams (research files)

Faults that offset glacial striae occur in several outcrops of greywackes beside the Mactaquac dam near Fredericton.

One 3-mm offset on a vertical joint is continuous with a small, mainly dip-slip fault. This suggests a small strike-slip (horizontal) displacement along the joint, but is inconclusive.

The report cites two possible explanations for the faulting: frost heaving or tectonic movements. (See also I.A.1.)

I.B.3
Bailey 1904

Caves are found along Corbett's Brook off the Saint John River just below Fredericton. Bailey ascribes rift-like fissures associated with the caves to postglacial differential movement. Firstly, the fractures are clean of glacial debris or drift. Secondly, a series of overhanging projections situated above the caves would, in his view, have sheared off under the weight of ice, had they existed in glacial times.

I.B.4
Basham and Adams 1984

A thrust joint offsetting glacially-smoothed bedrock was discovered about 0.5 km southwest of Indian Lake, northern New Brunswick. The joint belongs to a minor orthogonal set that may have resulted from a post-Triassic stress field (see I.B.6).

The joint fracture trends 005° and dips 40° west. It shows 25 mm of reverse displacement, west side up, and was traced for about three metres across the outcrop. However, thrust displacement disappears one metre north, and within a few metres south, of the outcrop.

The authors conclude that displacement is a secondary stress relief feature along a pre-existing joint rather than a primary rupture.

Adams (1987) locates the joint at latitude 46.99° and longitude 66.60°.

I.B.5
Fyffe 1983

Two fractures along pre-existing joints are located just southwest of Indian Lake near the Miramichi earthquake epicentre, and show evidence of postglacial movement.

The first fracture belongs to an orthogonal set that trends north (350° to 010°) and has an average dip of 40° to 50° west. The fracture shows a reverse displacement that offsets glacial striations by 2 cm, and can be traced for about 5 m.

The second fracture does not displace striae, but does have a fresh, angular appearance consistent with postglacial movement (L. Fyffe, pers. comm.). Displacement comprises about 4 cm of upthrusting over a length of 3 m. The joint belongs to a set that trends northward (345° to 000°) and dips east, most commonly between 50° to 80°.

(This entry describes the same features reported in I.B.4.)

I.B.6
Lajtai and Stringer 1981

Deformed Carboniferous sandstones east of Saint John have two prominent orthogonal joint systems with microcrack alignments parallel to four joint sets. In one system, the joint sets strike close to 010° and 100°. These are interpreted as post-Triassic in age. They also are postulated to represent release and load-parallel joints resulting from contemporary crustal stresses in eastern North America (i.e. east-west compression).

C. POP-UPS, BUCKLES AND ROCKBURSTS

New Brunswick

I.C.1
Basham and Adams 1984

In September 1983, overburden was removed from an area measuring 3000 square metres and located 0.5 km southwest of Indian Lake, northern New Brunswick. Removal was to facilitate mapping a 25-mm bedrock thrust, discovered after the January 1982 Miramichi earthquake (see I.B.4 and I.B.5). Shortly after overburden removal, the outcrop developed two buckles or pop-ups.

One thin slab of diorite, measuring 3 m by 1 m, arched up 55 mm from the underlying bedrock. The separation increased to 80 mm within a few weeks (Fyffe 1983). Trend of the buckle was 010°.

The pop-up represents about 5 MPa of east-west horizontal compression (Adams et al. 1984). This, together with the nearby small thrust fault, confirms the horizontal, east-west P axes deduced from the Miramichi mainshock and composite focal mechanisms. It also supports stress measurements taken from the Brunswick Mining and Smelting No. 12 mine (see VII.A.4).

A second incipient buckle appeared. Vertical separation from the underlying rock was only a few millimetres.

I.C.2
McKay et al. 1985

Eleven documented daytime rockbursts occurred in 1984 on the main outcrop of the Miramichi epicentral block during borehole drilling (see VII.A.5). Eight took place on May 20, two on May 27 and one on June 1. As well, several undocumented rockbursts appeared overnight during the same time period.

Two types of bursts were observed. Type I events were explosive pops, covered areas measuring about 20 cm, and sometimes involved flyrock. Type II events sounded less percussive, covered larger areas (several square metres) and involved no flyrock.

I.C.3
McKay et al. 1985

Two pop-ups are located on the main outcrop of the Miramichi epicentral block. The first appeared shortly after the outcrop was cleared in September 1983. It grew following the May 20 sequence of rockbursts (see I.C.2) and again after the May 27 events. The second pop-up developed after May 20.

Both pop-ups lie on the surface of a thrust fault footwall. As well, both indicate a compressive strength oriented at approximately 290°.

A bulging rock layer suggesting an incipient pop-up was seen on the main outcrop, but might well have been caused by nearby rockbursts.

I.C.4
Stead 1906

In the early 1900s, a grindstone quarry was worked in Pennsylvanian sandstone at Stonehaven on the south side of Chaleur Bay, New Brunswick. Quarrymen found that, as they cut the first channel 2 inches to 3 inches wide, the rock faces would creep together by about 1.5 inches. Occasionally, differential strain on cut and uncut portions of the bed would cause large chips to spawl off.

The sandstone bed trends parallel to Chaleur Bay in a near east-west direction. Creeping was particularly noticeable on cuts made perpendicular to the shoreline, thus suggesting an east-west compressive stress.

Nova Scotia

I.C.5
Janes 1978

The author describes igloo-shaped pop-ups in an abandoned gypsum quarry at Cape North, Cape Breton Island.

I.C.6
Notley 1980

For forty years, some 525 rockbursts or 'bumps' were recorded in the No. 2 Mine of the Cumberland Railway and Coal Company Limited, Springhill, Nova Scotia. A disastrous final bump in 1958 killed 75 men and forced the mine to close.

Notley attributes the bumps to a combination of geological and engineering factors. These can be summarized by saying that they were the natural consequence of attempting to mine economically at great depth in comparatively weak rock. While faulting may have influenced the location of some bumps, there is no evidence that earth tremors led directly to bump occurrence.

In late 1955, attempts were made to measure stress changes in the coal seam on the 11,800-foot level. Once the drill reached a depth of about 30 feet, however, the rods became stuck. Upon removal of the drill, the hole would partially collapse, preventing any subsequent re-drilling. The volume of cuttings produced far exceeded the volume of the hole. Also, audible snapping noises were noted during drilling. Both observations suggest that the rock was under considerable residual strain.

(See also Rice 1924).

I.C.7
Feld 1966

An abandoned granite quarry lies on Vinylhaven Island, 56 km south of Mount Waldo, Maine. While the quarry was active, a solid sheet of rock at a depth of 45 m buckled up about 1 m and 'exploded'. Rockburst occurrences became so commonplace that quarry operations eventually ceased.

I.C.8
Lee et al. 1979

Numerous destructive rockbursts occurred over the years in the granite quarries of coastal Maine. A report by Dale (1907), quoted in Lee et al., cites a rockburst that took place in the late 1890s at the main Mount Waldo quarry. The burst apparently was triggered by cutting a channel 3 m deep. Part of the sheared and crushed fracture zone can still be seen today in the east wall of the quarry. It is 2 m wide, 10 m long, 3 m deep, and strikes 28° northwest.

D. REGIONAL CRUSTAL WARPING

New Brunswick

I.D.1
Rampton et al. 1984

Broad regional uplift affected New Brunswick during the Late Cenozoic after pediplain formation. Locally, uplift was not uniform, and may have involved some block faulting.

The Musquash Lowland and Mispec Plateau both probably belong to the Tertiary peniplain. Their divergent elevations across Saint John Harbour indicate differential uplift and faulting between these areas. Similarly, the Tertiary pediplain terminates sharply at the Chaleur Bay coast at elevations between 150 m and 300 m, suggesting a tectonic origin for the bay.

Nova Scotia

I.D.2
Critchley 1976

Evidence was found for water subsidence (coastal uplift?) along the northwest side of Antigonish Harbour, Nova Scotia, but none on the south side. Differential uplift might be related to movement along the faults that parallel both sides of the harbour. Conversely, it could be an apparent phenomenon caused by recent deposition in shallow areas on the northwest side of the harbour.

I.D.3
Grant 1987

The paleoshore at Cape Cove, southwest Nova Scotia, has been upwarped by differential crustal rebound from present tide level near Red Head to 45 m near Digby.

I.D.4
MacNeil 1951

Elevations are given for the many raised beach localities in the Wolfville area in Nova Scotia. Although MacNeil does not mention the possibility of differential upwarping, the various levels cited for each locality are in some instances so fluctuating as to be suspicious. Detailed height mapping of these raised beach might prove fruitful.

I.D.5
Swayne 1952

An elevated beach at Specht Cove near the village of Barton in southwestern Nova Scotia can be traced for about 3 miles. The beach sits 150 feet above present sea level. The corresponding beach at Digby Neck, however, sits over 200 feet above sea level. Differential isostatic upwarping is believed to be the cause of the discrepancy.

I.D.6
Wightman 1980

A raised beach at West Advocate, Nova Scotia, on the north side of the Minas Basin sits at 35 m, 6 m higher than one in nearby Advocate Harbour. The distance is considered insufficient to ascribe the difference to crustal tilt. Instead, it is postulated that West Advocate Beach was deposited during a higher sea level.

CHAPTER II: FAULTING AND DEFORMATION OF GLACIAL AND POSTGLACIAL DEPOSITS

A. FAULTS AND SLUMPS

Numerous faults and slump features in unconsolidated sediments can be found across the Maritime Provinces. Undoubtedly, most if not all are true ice contact deposits in which bedding deformation followed the melting of supporting ice blocks. Before being dismissed as neotectonic indicators, however, they should be plotted on structural geology maps and re-examined in the light of possible structural association.

New Brunswick

II.A.1

References in this entry contain single line citations of deformed Quaternary sediments in New Brunswick. The more detailed descriptions follow as individual entries.

Reference	Location and Description
Finamore 1977	minor faulting in glacial outwash at UTM 929 076 in Charlotte County
Finamore 1979a	faulted and contorted ice contact deposits at UTM 595 024 and 556 092 in Restigouche County
Finamore 1979b	contorted ice contact deposits at UTM 035 805 in Restigouche County
Finamore 1981	contorted ice contact deposits at UTM 531 077 in York County
Finamore 1981	minor faults in ice contact deposits at UTM 967 201 and UTM 123 154 in Carleton County
Finamore 1981	minor faults in glaciofluvial outwash/ice contact deposit at UTM 139 182 in Carleton County
Finamore 1981	minor faults in glaciofluvial outwash at UTM 004 171 in Carleton County. Possibly caused by heavy equipment movement during excavation of pit.
Finamore and Lohse 1977	faulted and contorted ice contact deposits at UTM 650 200 in Saint John County
Hunter and Lavergne 1982	deformation structures in ice contact deposits at UTM 971 886 in Carleton County
Hunter and Lavergne 1982	slump structures in glaciofluvial deposits at UTM 336 905 in York County
Lohse 1977	contorted ice contact deposits at UTM 066 064 in Saint John County
Lohse 1977	faulted ice contact deposits at UTM 106 079 in Saint John County
Ruitenberg and Thibault 1981	faulted and contorted glaciofluvial deposits near Westfield
Seaman 1981	minor postdepositional faults in ice contact complex at UTM 925 036 in York County

Seaman 1987	abundant structures in glaciofluvial outwash delta at UTM 683 122 in Saint John County
Seaman and Thibault 1981	deformation structures in alluvium at 668 916 in York County
Thibault 1979	extremely deformed and faulted ice contact deposits at UTM 428 367 in Madawaska County
Thibault 1979	slumped and deformed ice contact beds at UTM 561 457 in Madawaska County
Thibault 1979	contorted bedding in outwash delta at UTM 453 536 in Madawaska County
Thibault 1979	contorted bedding in kame deposit at UTM 684 794 in Madawaska County
Thibault 1979	slumped and faulted ice contact deposits at UTM 699 455 and UTM 737 403 in Madawaska County
Thibault 1980	slumped bedding prevalent in ice contact deposits at UTM 060 854, UTM 936 108 and UTM 954 089 in Victoria County; and at UTM 996 217 in Madawaska County
Thibault 1981	faulted esker beds at UTM 566 559 in York County
Thibault 1982	faulted outwash/ice contact deposits at UTM 361 099 in Charlotte County
Thibault 1983	slumped ice contact deposits at UTM 685 353 in Charlotte County
Thibault 1983	slumping of beds and disturbed stratification at UTM 776 166 in Charlotte County
Thibault 1985	slumped and faulted ice contact deposits at UTM 245 602 in Restigouche County
Thibault 1987a	deformed ice contact deposits at UTM 335 654 in Gloucester County

II.A.2
Adams (unpublished report)

Normal faults were observed in glacial outwash sands at the junction of McGraw Brook and Holmes Lake roads, near the Miramichi epicentral area. Deformation was attributed to slumping caused by buried ice melt.

II.A.3
S. McCutcheon (pers. comm.)

Glacial deposits in a gravel pit at the end of the Sandy Cove Road in West Saint John show evidence of vertical movement. Deposits are locally offset by faulting.

II.A.4
Melvin 1966

Ice contact deposits are widespread throughout the Ben Lomond area near Saint John, New Brunswick. One of them, the Little River Delta between Silver Falls and Black River Road, exhibits varying degrees of deformation including normal and reverse faults, folds and slumps. Deformation is attributed to gravitational slumping produced by ice block melting.

The author considers crustal movements, related or unrelated to isostatic uplift, as a possible alternate cause of deformation. However, he also believes that selective deformation due to crustal movements most likely would appear as subaqueous slumping of the delta front. Subaqueous slumping generally creates intraformational deformation, rather than the observed widespread folding and faulting.

II.A.5
Northeast Utilities Service Company 1984

A bedrock fault was found to coincide with a VLF EM anomaly about 0.75 km northeast of Indian Lake, New Brunswick. The authors noted disturbed Late Wisconsin glacial till within and surrounding the fault. They attribute the disturbance to one or both of glacial action or fault movement.

(This report is a synopsis of the data in II.A.11 and II.B.5.)

II.A.6
Rampton et al. 1984

Thick faulted and folded glaciofluvial sediments occur east of Saint John, and west along the Bay of Fundy coast as far south as Campobello Island. Faults also are present in marine sediments overlying the glaciofluvial deposits. Faulting is ascribed to buried ice blocks that melted after general deglaciation of the area.

II.A.7
Ruitenberg (in press)

Folds, and normal and reverse faults are found in glacial and postglacial deposits along the Bay of Fundy coastline, southwest New Brunswick. Fault orientations are similar to those of regional bedrock faults, and contrast with irregular faults caused by glaciotectonics.

II.A.8
Ruitenberg et al. 1975

Numerous small faults are exposed in outwash deposits in the East Musquash watershed district, New Brunswick.

II.A.9
Seaman 1982a

Several Quaternary deposits in the Burtts Corner area, New Brunswick, show evidence of postglacial movement. One is located at the east end of the Durham Bridge outwash deposit. There, minor local faulting occurs in 10 m of horizontally stratified sand and gravel with minor cut and fill structures.

A large pit excavated in ice contact deposits found in the Penniac Brook valley northwest of Mount Hope also shows minor postglacial faulting. A third example of localized postglacial faults can be seen in the Keswick proglacial delta.

II.A.10
W. Take (pers. comm. in J. Adams research files)

Offset fractures in excavated bedrock were observed along sewer trenches in Fredericton. Offsets averaged 2 cm to 3 cm, but reached up to 12 cm of displacement. They apparently showed both horizontal and vertical relative displacement, as did the overburden that lay directly above the fracture plane. The trenches have since been backfilled.

II.A.11
Weston Geophysical Corporation 1984

Tectonic faults were exposed in two of three trenches excavated in 1983 over a VLF anomaly detected in the 1982 Miramichi epicentral area. Weathered and unweathered Wisconsin till overlaid the bedrock. Detailed mapping of the trenches revealed two types of soft sediment deformation, both indicating neotectonic movement. These were:

1. offset and sheared till
2. injected till (see II.B.5 for injected till description.)

Trench I exposed three main fault breccias, one of which trends 49° and dips 70° west. It is associated with offset and sheared till.

Several features indicate that the fault was offset after till deposition.

1. The till/weathered rock contact is about 1 m higher west of the fault than east of it.

2. Breccia on the north wall of the trench is raised about 6 inches relative to the adjacent gouge. Uplift appears to have occurred after till deposition: bedrock is sheared horizontally across the gouge and is also raised.

3. Breccia and weathered rock emplaced into the till seems to have been sheared horizontally.

(Compare this description and its associated entry, II.B.5, with entries II.A.20 and II.B.7 concerning very similarly described bedrock/till deformation on Sears Island in Maine.)

II.A.12
Lamothe 1986

Sheared organic matter was seen at the base of the upper till of a two-till sequence in a trench near Todd Mountain, New Brunswick.

Nova Scotia

II.A.13
Hickox 1958

A sand pit in deltaic deposits is situated about 1 km north of Kingston, Nova Scotia. Some reverse faulting has been observed in the pit.

II.A.14
Kindle 1917

Soft sediment deformation was seen in unconsolidated muddy sediments near the junction of the Avon and St. Croix rivers, about 70 km west of Halifax. Here, horizontal silt beds showing no deformation are 'sandwiching' a bed of highly distorted and deformed sediments. Height of the contorted layer is estimated to be one foot or more.

Kindle attributed deformation to differential weighting involving beds of dissimilar composition, acting together with bottom scour to produce horizontal movement. R. Dalrymple, however (J. Adams correspondence, 1981), observes that deformed beds in the area are rarely overlain by sand. He believes that winter ice action, including the grounding and pushing of stranded ice blocks, probably caused the deformation.

II.A.15
Stea et al. 1985

Glaciofluvial sediments of the Apple River Formation commonly show local faulting and deformation. The type section for the formation lies in a gravel pit north of New Salem, Nova Scotia, 3 km south of Apple River on the north shore of the Minas Basin.

II.A.16
Thorpe 1958

A Pleistocene deposit south of East Tremont, Nova Scotia, shows soft sediment deformation such as small displacements or faults. The site lies in the Berwick map area.

II.A.17
Wightman 1980

Faulting, liquifaction and slumping occur in glaciomarine and glaciofluvial sediments along the north shore of the Minas Basin. The area is bound to the north, and in places cut across, by the Cobequid Fault. Some deposits overlie north-south trending bedrock faults that have experienced at least post-Early Jurassic movement (Donohoe and Wallace, 1979b and 1980).

Deposits showing the most notable deformation features are described below.

1. Lower Five Island Delta:
Foreset facies show normal faults with a 60° east dip and a 1-m diplacement. Movement of underlying bottomsets probably caused faulting. Bottomset facies display low amplitude folds, overturned to the east. Proximal and distal sections of the bottomset facies show significant amounts of postdepositional movement. Folding directions in both sections indicate an east-west shortening or compression. Bottomset failure is attributed to underconsolidation.

2. Port Grenville Delta:
Bottomset beds show possible flowage. Delta has multiple foreset beds, attributed to rapid subsidence of the delta. Instability of the delta is related at least partly to water depth.

3. Spencers Island Delta:
Bottomset beds are heavily affected by normal and reverse faulting showing displacements of less than 1 m, and by larger magnitude slump faults. Bottomset facies also show some liquifaction in a 30-cm horizon. Contorted sediments appear to have been deformed while in a liquified state. As in the Lower Five Island Delta, bottomset failure is attributed to undercompaction.

Maine

II.A.18
Caldwell and Weddle 1983

Minor normal and reverse faults are evident in interbedded silt and clay layers located along the Sandy River near New Sharon, Maine.

II.A.19
Genes and Newman 1980

Large scale recumbent folding and thrust faulting can be seen in outwash deposits in a pit located about 1.5 miles from the Frenchville town line in northern Aroostook County, Maine.

II.A.20
Gerber 1979

Two trenches were excavated on Sears Island, Maine, through glacial deposits and into bedrock. They both exposed severely weathered Penobscot Formation phyllite. Contact between bedrock and till indicates minor compressional deformation in the form of intrusion features, thrust faulting and shearing.

One trench contains the intrusion feature, which is described in entry II.B.7. Thrust faulting and shearing are evident in the second trench, and appear as follows:

1. On the northeast wall of the trench, a 1-inch reverse fault dipping southeast displaces a till/bedrock contact estimated to be pre-Laurentide, over 52,000 years old.

2. On the southwest trench wall along strike, basal layers of pre-Laurentide till show minor crumpling with no evidence of bedrock deformation.

Deformation is ascribed to compression of incompetent rock in the weathered fault zone, as a result of base shear and stress distribution under glacial loading.

(Landsat images reveal a prominent lineament on Verona Island in

Penobscot Bay. The lineament trends towards the Sears Island fault mentioned above (Rogers 1980).)

II.A.21
Newman 1979

Newman examined glacial overburden and bedrock in the vicinity of the Oak Bay Fault in Maine for evidence of recent movement. He reports finding no faulted or deformed sediment layers, other than those created by slope failure.

Newman, however, continues with the observation that any evidence for recent movement along the fault would be quickly obliterated by coastal erosion of shattered bedrock, and by mass wasting or tree throw on the unconsolidated mantle.

II.A.22
Retelle and Konecki 1986

Outwash sediments in Webber Pit are deformed by low angle thrust faults and recumbent isoclinal folding, particularly at the top of the sands. The pit is located in the lower Androscoggin River valley on Route 196 near Lisbon Falls, Maine. The nearby Tupper gravel pit also contains locally deformed outwash deposits.

II.A.23
Smith 1984

Surficial sediments in the Grand Falls Lake area, Maine, were examined for evidence of Holocene faulting or other crustal movement. The area is transected by three or four faults that trend almost east-west.

No clear evidence exists for any large- or small-scale movement on these faults. At one locality, however, an esker is breached at a position where it intersects an inferred fault. The offset most likely results from the manner in which the esker was formed, but could represent postdepositional displacement by faulting.

II.A.24
Thompson 1981

Excavation along the strike of a vertical fault near the Norumbega Fault Zone in Maine revealed a fault in the overlying till. A vertical fracture extends from the fault up into the till for about 10 cm. The till fault is believed to be a continuation of the bedrock fault.

The bedrock fault trends 85°. UTM grid coordinates for the locality are 5023550 m N, 620450 m E.

B: INJECTION FEATURES

Injection features is a general term used here to cover intrusion features such as flame structures, sand intrusions and sand dykes. It also refers to: blocks or veins of till that have been injected into bedrock fractures; till that has been injected with bedrock material such as breccia; and till wedges.

New Brunswick

II.B.1
Adams (unpublished report)

An open crack at site m994 of an excavated trench near the Miramichi earthquake epicentre (see I.B.1) is 60 mm wide and 1.2 m deep. Small stones and a large block broken from the right wall are wedged tightly in the fracture. The crack apparently closed slightly after its initial opening.

II.B.2
Chiswell 1986 and 1987

Outwash deposits on the Mascarene Peninsula show substantial deformation features such as sand dykes, flame structures, folds and reverse faults. One deposit is in a gravel pit on the south side of Magaguadavic Harbour about 3 km southwest of St. George (P. Chiswell, pers. comm.). Other pits occur along the Digdeguash River.

II.B.3
Ruitenberg (in press)

Faults and well developed silt injections are found in glacial and postglacial sediments along the Bay of Fundy coast, southwest New Brunswick. Deformation could have resulted from dewatering after rapid loading by landslides and/or overriding glaciers.

Landslides in the area potentially could be triggered by seismicity centred along nearby major structures (e.g. the Cobequid-Chedabucto or Oak Bay fault systems).

II.B.4
Ruitenberg et al. 1975

Outwash strata in the Musquash watershed area has been deformed by flame-like sand intrusions. They probably result from upward movement of water saturated sediments above high pressure aquifers, which were partly disrupted by faulting in the outwash deposits.

II.B.4a
Seaman and Thibault 1986

Flame structures were noted in contorted alluvial deposits at UTM 140 947 in Sunbury County.

II.B.5
Weston Geophysical Corporation 1984

Tectonic faults were exposed in two of three trenches excavated in 1983 over a VLF anomaly detected in the 1982 Miramichi epicentral area. Weathered and unweathered Wisconsin till overlaid the bedrock. Detailed mapping of the trenches revealed two types of soft sediment deformation, both suggesting neotectonic activity. These were:

1. offset and sheared till (see II.A.11)
2. injected and wedged till.

The injected and wedged till appears as follows:

1. Trench I exposed three main fault breccias, one of which trends 40° and dips 70° west. It is associated with deformed till. Gouge and breccia from the fault described above appear to have been injected into the overlying till in a plastic manner. A fault zone in Trench II shows a similar effect and is assumed to be an extension of the first fault mapped in Trench I.

2. The fault in Trench I contains a large wedged block of basal till that includes striated pebbles. The till projects down about 2 m from ground surface. The feature likely cannot be ascribed to glacial action alone (Northeast Utilities Service Company 1984).

(Compare this description and its associated entry, II.A.11, with entries II.A.20 and II.B.7 concerning very similar bedrock/till deformation on Sears Island in Maine.)

Nova Scotia

II.B.6
Mörner 1973

Several till wedges were discovered in the Milford gypsum quarry near Shubenacadie, Nova Scotia. Wedges of red clayey till up to half a metre long were seen injecting down into yellow sand. Wedging was credited to the cracking and filling mechanism (Mörner 1972), but could possibly be related to liquifaction caused by postglacial seismicity (Seeber et al. 1985).

Maine

II.B.7
Gerber 1979

Two trenches were excavated on Sears Island, through glacial deposits and into bedrock. They both exposed severely weathered Penobscot Formation phyllite. Contact between bedrock and till indicates minor compressional deformation in the form of intrusion features, thrust faulting and shearing.

One trench contains the thrusting and shearing features described in II.A.20. The intrusion appears in the second trench, and comprises plastic weathered phyllite intruded 6 inches up into the till. The till is estimated to be 16,500 to 22,000 years old.

Deformation is ascribed to compression of incompetent rock in the weathered fault zone, as a result of base shear and stress distribution under glacial loading.

II.B.8
Thompson 1981

A granitic outcrop just north of Amazon Lake in the Scraggly Lake quadrangle contains open fractures filled with till veins. The fractures show vertical offsets of 5 mm or more, which do not extend up into the overlying till. Till injection probably occurred during slight movements along the granite joints during the last glaciation.

II.B.9
Thompson 1986

Low angle thrust faults are locally evident in several gravel pits located in the White Mountain foothills, southwest Maine. One in particular, the Hatch Hill pit, contains 2 m to 8 m of stratified glacial diamicton that contains odd structures. They appear as vertical fissures or cylindrical openings that were somehow eroded and then filled with sand and gravel.

C. OFFSET WAVECUT BENCHES AND STRANDLINES

Nova Scotia

II.C.1
Grant 1975a

In Aspy Bay on Cape Breton Island, a pre-Wisconsin marine bench can be followed continuously for several kilometres southward from Cape North. At the Aspy Fault Zone, however, it changes height over a few metres, reappearing on the south side at twice its average elevation. No higher benches are known in the area. (See II.C.2 and II.C.3 for updated versions of this paper.)

II.C.2
Grant 1985

A wavecut bench standing 4 m to 6 m above the modern abrasion platform that rims Nova Scotia (and Newfoundland).

Where the bench crosses the Aspy Fault on Cape Breton Island (and also where it crosses Newfoundland's Cape Ray Fault) the platform is upthrown by several metres.

Significantly, the feature is absent on the Nova Scotia coast south of the Chedabucto Fault. Smaller scale faulting occurs in cleavage slates near Yarmouth, implying deglacial elastic rebound.

II.C.3
Grant (in press)

An extensive raised shore platform found at 7 m around northern and western Cape Breton Island ends abruptly at a branch of the Aspy Fault. It continues immediately south of the fault at 22 m. The discontinuity represents a 15-m offset due to uplift of the Aspy Basin relative to the Cape Breton Highlands block, sometime within the last 125,000 years.

Of all possible causes, local isostatic adjustment linked to deglaciation or erosional compensation are perhaps most likely. However, deep seated crustal tectonics also may be involved.

II.C.4
McLeod 1973

Thick accumulations of glacial and peat deposits southwest of the Oak Bay Fault are absent on the northeast side. This apparent change in surficial geology suggests that recent dip-slip movement has occurred on the Oak Bay Fault.

II.C.5
Neale 1963a

Tilted, wavecut rock benches along the coast at Pollett Cove, Cape Breton Island, are overlain by stratified fluviatile deposits. The benches sit about 35 feet above sea level, attesting to postglacial uplift. Faulting related to postglacial uplift has slightly displaced both the bedrock of the benches and the overlying fluviatile sediments.

II.C.6
Neale 1963b

Tilted, wavecut rock benches are overlain by stratified fluviatile deposits at Sugar Loaf in Aspy Bay, Cape Breton Island. They can be traced from there northeastward along the coast. As at Pollett Cove farther south, the benches sit about 35 feet above sea level, suggesting postglacial uplift. Faulting related to postglacial uplift has slightly displaced both the bedrock of the benches and the overlying fluviatile sediments.

II.C.7
Neale 1964

Near Cape North at the northern tip of Cape Breton Island, wavecut rock benches range in elevation from 3 feet to 20 feet, possibly due to postglacial faulting of an original beach at about 20-foot elevation.

CHAPTER III: MASS SUBSIDENCE

A. KARSTS AND SINKHOLES

New Brunswick

III.A.1
Bailey 1904

This lengthy report provides lyrical accounts of the many caves across New Brunswick. Most references are to solution caves in gypsum and limestone, some measuring 30 m across and 15 m deep. The ever-present possibility of mass subsidence notwithstanding, these features have more spelaeological than neotectonic application.

III.A.2
McAlpine 1983

All solution caves in New Brunswick are found in either Precambrian limestones of the Greenhead Group, or Mississippean limestones of the Windsor Group. One known tectonic cave in Fundy National Park was formed by gravity sliding.

The paper list fifteen New Brunswick caves, and also cites other references describing caves in the Atlantic Provinces.

III.A.3
McCutcheon and Thibault 1981

Sinkholes, believed to be postglacial, are common around the Sussex region in the Upperton Formation (mainly gypsum and anhydrite). The most potentially hazardous area is along the Cougle Road, and south of Highway 111.

III.A.4
Schroeder and Arseneault 1978

Two small gypsum-anhydrite basins containing a confined 'merokarst' are situated on the west side of Petitcodiac River south of Moncton. The northern basin emcompasses sinkholes, dry valleys, caves and sinks. Except for one sinkhole, which dates back to a Wisconsin interstade, the karstic landforms are Holocene.

III.A.5

Karstic sinkholes also have been noted at the following localities in New Brunswick.

Reference	Location and Description
Hamilton 1962	A narrow belt of sinkholes lies in the extreme southeast corner of the Codys map area in south central New Brunswick.
Hamilton 1968	A line of sinkholes in limestone delineates a fault found along Bonny Road in the Nauwigewauk area, Kings County, New Brunswick.
Manzer 1947	Numerous sinkholes are found near the bend of the Hammond River near Upham, Kings County. They occur in gypsum of the Upham Formation.
White 1987	Several sinkholes in gypsum are situated on the north side of Route 860 southwest of Sussex. Some have attained dimensions of about 3 m across and 1.3 m deep.
Wright 1950	Areas of limestone are common in the Saint John district. They are characterized by underground caves that occasionally collapse and disturb overlying structures.

Nova Scotia

III.A.6

Karstic sinkholes have been noted at the following localities in Nova Scotia.

Reference	Location and Description
Boehner 1981	A paleokarst or modern solution collapse zone is located in Loch Lomond Basin, Cape Breton Island, near the Kaiser celestite mine.
Carter 1986	Karst topography is found near the Pugwash salt mine, Cumberland County.
Crowdis 1969	Sinkholes occur in gypsum on the south side of Antigonish Harbour.
Goodman 1952	Sinkholes occur at the Magazine Quarry and Western Area in Little Narrows, Victoria County; and near gypsum quarries at Walton, Hants County.
Hilton 1953	Many sinkhole ponds are found in gypsum in Williams Point area, Antigonish County.
Neale 1955	Karst topography occurs near North Pond in Pleasant Bay map area.
Norman 1935	Many sinkholes are found in gypsum on Hood Island, and also near Glendyer Station in the Lake Ainslie area.
Norman 1935	A gypsum belt measuring 100 m to 120 m wide extends for about 3.2 km along the coast at the Mabou Mines, Lake Ainslie area. It is broken by numerous sinkholes throughout its length.
Wait 1959	Karst topography is well developed in gypsum belts at Finlay Point, Coal Mine Point, West Mabou Harbour, Murphie Point, Glendyer Station and between Mabou Harbour Mouth and Northeast Mabou.

B: KETTLES

New Brunswick

III.B.1

Kettles have been noted at the following localities in New Brunswick.

Reference	Location and Description
Gadd 1971	deep kettles in gravel deposits near Utopia Centre and Pennfield Ridge, southwest N.B.
Melvin 1966	kettles in ice contact deposits in the Ben Lomond area near Saint John
Rampton and Paradis 1981a	kame-and-kettle complexes near Arnfield, Limestone, Plaster Rock, Tilley and other locales
Rampton and Paradis 1981b	kame-and-kettle complex near Third Lake at head of Loch Lomond system
Ruitenberg et al. 1975	kettles common in outwash deposits in East Musquash watershed area
Seaman 1982b	kettles found at UTM 438 481 in York County
Seaman and Thibault 1986	kettles in outwash deposits at UTM 504 681 in Kent County
Thibault 1983	kettles in outwash in Charlotte County, UTM 615 300

Nova Scotia

III.B.2
Grant 1980b

A kettle is associated with a glaciomarine delta at Sandy Cove, southwest Nova Scotia. Goldthwait (1924) and Dunlop (1952) describe the same large kettle and several smaller ones on top of a kame terrace in Sandy Cove, Church Point area.

III.B.3
Wightman 1980

Two large kettles occur on the west side of the Portapique River. One measures 1.4 km by 0.4 km, and is south of the highway. The other is 0.8 km by 0.3 km, and lies just north of the highway. Both are elongated in a north-south direction.

Wightman describes other kettle locations in the map area, along the north shore of the Minas Basin. These are plotted on maps accompanying the report; several examples are listed below. All are elongated east-west, unlike the Portapique occurrences.

Location	Description
in outwash deposits east of Economy Point Road	one kettle is 500 m long; another is 300 m by 75 m
in outwash delta near Diligent River	two groups of kettles lie along the Ramshead River; one kettle is almost 11 m deep
in deltaic deposits on west side of Fox River	one kettle measures 100 m across and 10 m deep; another lies north of highway in Wards Brook

C: MINE SUBSIDENCE

Nova Scotia

III.C.1
Anonymous 1983

Three instances of coal mine subsidence are reported near River Hebert, Nova Scotia. Two occurred in December 1981: one over the Cochrane Mine fan shaft, and the other over the Cochrane No. 1 Mine. A third subsidence took place in May 1983 on the property of D. Martin.

III.C.2
Anonymous 1985

This report documents several hundred hazardous and potentially hazardous mine openings across Nova Scotia, relating the data to possible subsidence effects.

III.C.3
Anonymous 1988

Several cases of mine subsidence involving the Springhill, Pictou and Sydney coal mines occurred in the summer of 1987. Structural damages resulted from subsidence at the latter two localities.

III.C.4
Cole et al. 1963

On May 25 and November 15, 1956, subsidence affected ground overlying the old Waverly gold mine workings. Both cave-ins occurred over shafts of the No. 6 Lead.

III.C.5
Pictou County District Planning Commission 1981

Subsidence of old coal mines in Pictou County, Nova Scotia, has caused minor to severe subsidence. Collapse of the Old Foord Mine workings has affected populated areas in Stellarton. The Black Diamond Mine near Westville is responsible for subsidence adjacent to the CNR line.

III.C.6
Townsend 1960

Sometime in April 1960, ground above the old Minedar Mine workings in Stirling subsided, leaving a hole about 12 m across. The hole lay 36 m southwest of the original mine shaft.

D: LANDSLIDES, ROCKSLIDES AND OTHER SUBSIDENCE

New Brunswick

III.D.1
Chiasson et al. 1973

A major easterly-trending bedrock depression was discovered near Saint John. It has been infilled with very fine, water saturated clay or silt. Although no rapid subsidence has yet been detected, the authors recommend that its foundation properties be thoroughly assessed before any construction be considered over the locality.

III.D.2
Hunter and Associates 1982

This four-part publication is a management study that comprises photographs (both recent and historic), maps and a report on the Fundy Coastal Zone. Volume IV, an atlas of 74 maps covering the study region, contains summary descriptions of each map site.

The descriptions include occasional references to landslides and mudflows. These are listed below. The occurrences probably resulted from normal gravity slumping and/or wave undercutting. However, minor seismicity also can trigger such phenomena.

Map No.	Map Name	Features
21	Taylor Peninsula	Arcuate slumping, landslides, mudflows and recent slumping occur east of Sheldon Point.
22	Saint John Harbour	South of Red Head, slumped marine deposits are prevalent along high bluffs. Continued toe undercutting by waves, combined with heavy rainfalls, triggers renewed slumping.
33	Salmon River	Debris flows and slumping occur in stratified marine deposits east and west of Long Beach Creek.
36	Martin Head	Slope failure, slumping and gullying occur in elevated marine deposits overlain by outwash west of Martin Head.

III.D.3
Legget 1980

In 1973 a small landslide was noticed in Deep Cove Brook on Grand Manan Island, about 0.8 km from the brook mouth. When revisited in 1974, the former exposure had been obliterated by subsequent landslides.

III.D.4
Rappol and Shilts (in press) and M. Rappol (pers. comm.)

A coarse diamicton overlies glaciolacustrine deposits of Glacial Lake Madawaska at St. Jacques on both sides of the Madawaska Valley.

The diamicton comprises large (over 1 cubic metre), very angular blocks of slate and some diabase. It apparently formed as a rock avalanche from glacially oversteepened rock walls of the valley. Many larger clasts have one flat, striated surface, perhaps as a result of having being fractured from a glacially moulded surface.

The deposit occurs at the same stratigraphic position on both sides of the valley, but has differing compositions and flow directions. It is suggested that some catastrophic event triggered the failure at both places. A seismic event seems the most plausible explanation.

III.D.5
Ruffman and Peterson (in press (a))

On 17 March 1870, an earthquake centred in eastern Maine, just west of St. Stephen, precipitated a landslide at Sand Point, southern New Brunswick. It carried the tip of the point out into harbour. The point was formed of gravel overlying clay, and aparently had been rendered unstable by a heavy storm one day earlier. (See III.D.10.)

III.D.6
Ruitenberg et al. 1976

Gravity slides involving unusually large blocks of rock occur at Devil's Half Acre, about 2.5 km southwest of Alma in Fundy National Park. The rate of block sliding may well exceed 20 cm per year.

Movement occurs mainly along a thin shale member that underlies well jointed sandstone and other strata of the Boss Point Formation. The bedding parting and perpendicular joints divide the formation into large blocks susceptible to gravity sliding. Minor seismic shocks, common along the Bay of Fundy, also may help to initiate the rock slides.

III.D.6a
Ruitenberg and McCutcheon 1978

On 27 November 1977, a landslide took place in Lorneville Cove on the Bay of Fundy, just southwest of Saint John. The slide involved a wedge of marine clay, silt and minor sand overlying a sloping surface of intensely fractured bedrock. It showed a well developed arcuate surface, but differed from other rotational slides in that failure originated above a sloping bedrock surface.

Movement occurred shortly after a period of heavy rainfall, which saturated the sediment and lowered its shear resistance. There is no evidence of accompanying bedrock movement. However, a coincidental weak seismic tremor detected by a local resident possibly may have triggered the slide.

III.D.7
Tarralle 1972

Unstable clays have contributed to many landslides in the vicinity of Red Head Cove, southern New Brunswick. Events in 1914, 1945, 1953, 1962, 1969 and 1970 affected areas ranging in size from about 1350 to 4430 square metres. (See also III.D.11.)

III.D.8
White 1987

Between 1984 and 1986, a 10-m section of Route 860 southwest of Sussex subsided about 1.2 m. Subsidence occurred near an intersection with a known fault, and over an underlying gypsum bed. Erosion of unconsolidated soil from pre-existing solution channels in the gypsum probably caused the instability.

III.D.9
Wright 1950

During the night of January 25-26, 1949, a large landslide occurred in the Lancaster Avenue area, Saint John, on the west bank of the Saint John River. The failure was about 400 feet wide and affected about 4.7 acres of land.

Sliding involved a thick deposit of unstable wet boulder clay overlying a buried valley ('glen') of glaciated bedrock. Evidence suggests that the glen experienced an earlier landslide sometime before 1889, and that the 1949 slide occurred over the old slide site. The later slide probably resulted from a combination of factors including removal of toe support by river erosion, and excessive rainfall.

Fourteen earth tremors shook the area between January 22 and January 30, breaking water mains, and cracking walls and chimneys. While post-failure events probably were caused by the landslide, pre-failure tremors may have been seismically related. The trace of a fault situated on the east side of the Saint John River passes close by the landslide edge.

III.D.10
Wright 1950

Sand Point lies on the west side of Saint John Harbour, about 1.6 km northeast of the Lancaster landslide (see III.D.9). On 17 March 1870, a large portion of the beach rapidly subsided by at least 9 m. Around the same time, the ocean bottom in the harbour centre was observed to rise by 6 m.

Although Wright did not attribute this subsidence to seismic activity, a recent report relates it to a concomitant earthquake (see III.D.5).

III.D.11
Wright 1950

An annual report presented to the Common Council for the year 1870 reports 'recent subsidence' that took place at Red Head east of Saint John. Circumstantial evidence suggests the subsidence occurred shortly after the Sand Point event (see III.D.10).

Nova Scotia

III.D.12
Cranton 1959

A cave-in occurred southeast of Northeast Margaree, Inverness County sometime in 1959. The subsidence was correlated to solution cavity collapse, as limestone and gypsum deposits are found throughout the district.

III.D.13
Hutt 1984

Small scale slumping of red clay and associated debris is common in the Avon River district. Sometime in mid-1945, a particularly large slump swept away the rails at Mile 40.1 on the Dominion Atlantic Railway line. Failure was attributed to a combination of causes, including wet clays, tidal erosion, overloaded clay beds, steep slope and traffic movement.

III.D.14
R. Boehner (pers. comm.)

Near New Waterford on Cape Breton Island, huge blocks of bedrock have fallen down onto the shoreline. The scale of movement is such that they are indicated as broken land on the 1:50,000 topographic maps. The bedrock is dissected by listric faults. These apparently extend down into a smooth clay bed that presumably lubricates the failures.

III.D.15
D. Grant (pers. comm.)

A large landslide measuring about 1.6 km across was noted on airphotos of the Big Intervale area, Cape Breton Island. The slide lies opposite Big Intervale, about 4 km from the Cabot Trail, and just northwest of the Aspy Fault.

III.D.16
Ogden 1980

Slope failure occurred on a delta during construction of the

Digby Tourist Bureau in southwest Nova Scotia. A large section of the sand beds underwent slumping.

III.D.17
Ruffman and Peterson (in press (a))

On 12 August 1832, an earthquake caused many rocks on the cliffs of Brier Island, Bay of Fundy, to tumble down. The epicentre is placed east of Windsor in Nova Scotia.

III.D.18
Ruffman and Peterson (in press (a))

An earthquake with its epicentre in the Moncton-Dorchester area was felt on 8 February 1855. It initiated a large landslide on the southeast side of Granville Mountain opposite Digby, Nova Scotia. Newspaper evidence suggests that slumping and downslope movement continued for some time after the main event. Liquifaction at the site may have triggered slow downslope movement.

III.D.19
Ruffman and Peterson (in press (b))

The 18 November 1929 Grand Banks earthquake caused a heavy landslide on the Ross Ferry-Kempt Head road, one mile west of Ross Ferry. Tons of debris from the south side of the road became dislodged, shifting the highway northward 300 feet from its previous position.

About 200 feet from the landslide, a fissure appeared in the bank. A stream became temporarily diverted into the fissure. It saturated the surrounding ground so greatly that another landslide occurred a few days after the first landslide.

III.D.20
Ruffman and Peterson (in press (b))

The highway at Black River in Cape Breton Island subsided about a foot for a distance of over a mile after the 1929 Grand Banks earthquake. The earthquake also 'unearthed' an old well in Sydney, Nova Scotia. Stonework was visible to a depth of about a metre, and it took several hours to fill in the cavity.

III.D.21
Rappol and Shilts (in press)

Subbottom acoustic profiling work done in Temiscouata Lake revealed a large slump of chaotic, fine grained sediments. The disturbance occurred in the central portion of the profundal plain, and was approximately 16 km across. Seismic triggering could have moved the sediments down the steep sides of the lake.

Alternatively, hydrologic or sedimentologic processes may have caused slumping.

III.D.22
Smith and Bridges 1983

An earthquake that occurred in the Grand Manan/Saint John area on 1 June 1885 caused rocks to fall from an unspecified cliff location.

III.D.23
Wait 1959

A large landslide scar lies midway between McKinnon Brook and Sight Point on the west Cape Breton coast. The slides, which occurred in the spring of 1930, completely removed several hundred feet of a bushroad that crosses the area.

III.D.24
Wait 1959

Landslide topography and rockslide grooving were observed on and near a steep hillside east of the point where McKinnon Brook Fault enters the sea on the west coast of Cape Breton. Landslides are seemingly common to the site, as evidenced by the series of parallel grooves in the hillside, tracing the course of regular rockslide descent.

Maine

III.D.25
Novak 1988

Airphoto analyses in Cumberland County, Maine, reveal numerous failures along slopes in rivers, estuaries and open bays. Failures occur in the silty clay of the Presumpscot Formation.

Most of the smaller (50 to 300 linear feet) slides seem to be recent. Although several larger ones (300 to 1200 linear feet) occurred in historic times, only one - the 1983 Gorham landslide - took place within the last century.

III.D.26
Novak et al. 1984

In September 1983, a seven-acre section of land slid and fractured into blocks along the north side of the Stroudwater River in Gorham, Maine. The slide moved southward, was 300 m long from east to west, and was 95 m wide. It affected the glaciomarine clays of the Presumpscot Formation.

Surface overloading by buildings and vehicles, together with well drilling activities in the area, may have triggered the slide.

III.D.27
Novak and Lepage 1986

The September 1983 landslide at Gorham, Maine initiated the compilation of a Maine landslide inventory. Information sources included engineers, geologists, public works directors and other personnel, plus literature references from old newspapers and additional archival data.

Thirty-three slides were discovered. Most occurred in the Presumpscot Formation, where it is exposed along the coast and streams. Slide widths ranged from 15 to 1000 feet, slide lengths from 15 to 500 feet, and headscarp heights from 1.5 to 60 feet. Slumps and soil flows were the most common slide type. Block and rockslides, earth flows and complex slope failures also were recorded.

III.D.28
Sandford 1988

The area around Westbrook, Maine, has experienced historic landslides covering up to 8 hectares, and prehistoric landslides covering up to 70 hectares. The slides occurred in the Presumpscot Formation along the Presumpscot River, and spread laterally for distances of up to 1000 m.

The slopes of Presumpscot Formation bluffs are unstable. Since the last major landslide occurred about 100 years ago, the area behind the bluffs has been very heavily developed. Analyses indicate that future river erosion, earthquakes, land regrading or other stresses could trigger a massive landslide.

CHAPTER IV: CHANGES OF SEA LEVEL

For the last 5000 years, most coastal areas of the Maritime Provinces have been submerging. The fact is supported by abundant evidence from the fields of geology, geodesy, hydrology, paleobotany and archaeology. Data also indicate that portions of the Maritimes underwent some postglacial emergence, the ever-shifting Quaternary sea reaching its upper marine limit around 14,000 to 11,5000 years B.P. (Wightman and Cooke 1978).

Submergence in the Maritimes is proceeding at about 30 cm per century - five times faster than the worldwide average. The greater rate is postulated to result at least partly from subsidence of the crust following the collapse of a former glacier-marginal bulge (Grant 1970b).

Along the Bay of Fundy coastline, an additional factor may be involved. As worldwide Quaternary sea levels rose, the Bay of Fundy entrance became widened and deepened. The resultant altered geometry amplified tidal ranges, and hence raised relative sea levels in the Bay. Between 7000 and 4000 years B.P., the tidal range increased by 30 to 50 per cent (Scott and Greenberg 1983).

A. SEA LEVEL CHANGES AND NEOTECTONISM

Sea level changes are critically, albeit indirectly, applicable to neotectonics. Put simply, coastal submergence takes place either because the land is subsiding, or because the sea is rising, or both. One of several components capable of causing land subsidence is deep seated tectonism. Grant (1970b) describes this component, and its relationship to other sources of coastal submergence:

> "One source of subsidence is crustal deflection caused by the [increased water load following the] postglacial eustatic rise of sea level. This mechanism accounts for most if not all of the submergence anomaly along the Atlantic coast of Nova Scotia.
>
> The Bay of Fundy, in contrast, owes about half of its excessive rate to differential rise of the high tide datum through increasing tidal range....Tidal amplification...commenced about 6000 years ago, but most of the differential accumulated during the last 4000-5000 years.
>
> Even after allowing fully for tidal change and water-loading, a residual submergence of 3-9 cm/century remains, parts of which could be a combination of additional subsidence due to geosynclinal downwarping and relaxation of a former ice-marginal bulge. **The inadequacy of all of these factors combined seems to implicate additional regional tectonism.**" (p. 687-688).

(Emphasis by present author.)

B. EVIDENCE FOR CRUSTAL SUBSIDENCE AND UPLIFT

Direct evidence for crustal uplift and submergence in the Maritimes is available from tidal gauge records and geodetic measurements. These references are detailed in Chapter VI, Part B.

The indirect evidence - raised beaches, submerged salt marshes and weathering profiles, inundated archaeological sites, drowned forests, fossil shells etc. - has been well documented and compiled by Grant and others. Any attempt to duplicate these excellent summary articles would be pointless. Their references, plus selected related papers, are provided below:

Amos 1977

Amos 1978

Amos et al. 1980

Goldthwait 1924

Grant 1970a

Grant 1970b

Grant 1975b

Grant 1977

Grant 1980a

Grant 1987

Honig and Scott 1987

Harrison and Lyon 1963

Kranck 1972

Merriam 1886

Prime 1980

Quinlan and Beaumont 1981

Scott and Greenberg 1983

Scott, Medioli and Duffett 1984

Scott, Medioli and Miller 1987

Smith, Scott and Medioli 1984

Stea 1987

Wightman and Cooke 1978

CHAPTER V: OFFSHORE GEOLOGY

Submarine geological data derived from investigations of the Canadian offshore can be used to expand our knowledge of onshore, continental rocks. This is particularly true in neotectonic studies. What submarine geology lacks in ease of access, it makes up for in preservation of recent sedimentation.

Onland, effects of erosion have all too often masked or removed signs of recent tectonic activity. The submarine environment, however, tends to preserve more of its neotectonic past - hence our ability to discern Cretaceous and Tertiary faulting over areas of the offshore margin.

Most of the currently available evidence for offshore neotectonism is in the form of slumps and slides. As mentioned, recent faulting also has been detected.

A. SUBMARINE SLUMPS AND SLIDES

Eastern Offshore

V.A.1
Buckley 1981

Piston cores were taken from depths of between 11 m and 12.8 m over an area measuring 10 square km on the Sohm Abyssal Plain. The cores contained a sand fraction at the base of the sequence. Benthic foraminifera species not indigenous to the deep sea environment occurred in the sand, indicating that turbidity currents had transported the sediment from the continental shelf.

The sand, which was dated at about 10,000 years B.P., also contained coal fragments. The fragments, plus the forams and heavy mineral analyses, suggest that the sand deposits resulted from a very active turbidity flow originating in the Scotian Shelf-Laurentian Fan area perhaps 10,000 years ago.

V.A.2
Burgess 1983

Thermal conductivity measurements were made over an area on the Sohm Abyssmal Plain. Survey results revealed substantially higher conductivities at the base of the piston cores. These correspond to a coarse sand-silt layer deposited by a major turbidity flow from the Grand Banks, possibly 10,000 years ago (see V.A.1). The sand-silt layer is more thermally conductive because it contains more siliceous detrital material.

V.A.3
Damuth et al. 1979

A 3.5 kHz echo sounding survey was made over the Nova Scotian continental rise at 39-42°N, 59-94°W. The upper portion of the lower rise (3700 m to 4000 m) produced prolonged echos at some sites, suggesting the presence of slump and/or debris flow complexes.

V.A.4
Embley and Jacobi 1986

J. Damuth (pers. comm., in Embley and Jacobi) reported three large submarine slide complexes detected during the HEBBLE (High Energy Benthic Boundary Layer Experiment) studies. Complexes are located at 40.5°N, 65°W; at 41.5°N, 64°W; and at 41°N, 63°W. The eastern complex is the largest of the three (1 km by 10 km), and comprises acoustically transparent wedges that probably are debris flow deposits. The western and central complexes are primarily block slide material.

(Damuth's pers. comm. in this entry may document the same slide complexes referred to in V.A.3.)

V.A.5
Finley 1978

Offshore sedimentary structures were surveyed southwest of Nova Scotia using seismic reflection profiling. Both slumping and faulting were recognized in the profiles. Slumping seems to have occurred only where the slope gradient was at least 4°; slumped material usually is deposited where the gradient decreases to about 2°.

V.A.6
Heezen and Drake 1964
(With additional notes from Heezen and Ewing 1952)

Following the 1929 Grand Banks earthquake, submarine cables lying downslope of the epicentral area broke sequentially from north to south over the next 13 hours and 17 minutes. Cables in the epicentral area, however, broke almost immediately.

Seismic reflection profiles were run in 1961 across the epicentral area of the earthquake. A large gravity slump was detected in the vicinity of the cable breaks.

It is believed that two separate events occurred: (1) the earthquake triggered a slump, which in turn caused immediate failure of cables in the epicentral area (2) the earthquake also initiated turbidity currents, which flowed downslope and created the later, sequential cable breaks described in Heezen and Ewing (1952).

Whether the turbidity currents resulted directly from the earthquake, or were slump induced, is uncertain.

V.A.7
Hill 1983
(With additional notes from Hill 1984)

Detailed bathymetric, seismic, and sidescan surveys were done over a small area in the Nova Scotian continental shelf at 42°50'N, 63°30'W. Survey results reveal a complex surficial morphology.

On the upper slope, large scale mass movements up to several kilometres in diameter have created a steep escarpment 150 m high. The accumulated debris below contains large coherent blocks of sediment up to 50 m thick. The midslope area is characterized by medium scale mass movements with relief on the order of tens of metres.

A small turbidity current channel also was identified in the study area. Piston coring suggests that mass movements and turbidity current activity occurred primarily in the Late Wisconsin, and ceased around 18,000 years B.P.

The author draws a direct relationship between slumps and turbidites, suggesting that turbidity currents and mass movements were active concurrently. Turbidite sands are often found within slump units, and the sudden deposition of sediment from turbidity currents may have caused slope instability. Significantly, Hill (1984) adds: "The problem of instability on a slope of such low angle (2°) has not been clearly resolved" (p. 307).

(See V.A.15 for discussion of observations.)

V.A.8
Hill et al. 1983

Two submersible dives were made over a 15 km by 20 km area on the upper Scotian Slope. The zone lies immediately seaward of a deep water saddle on the shelf between the Emerald Bank and LaHave Bank. Evidence of surficial slumping was observed in the form of allochthonous blocks and slump scars. (See V.A.15 for discussion of observations.)

V.A.9
King 1975

King describes a large, fairly recent slump and other major slump blocks in Mesozoic-Cenozoic sediments in unspecified sites on the continental margin south of Nova Scotia.

V.A.10
MacLean and King 1971

A terrace located at depths of between 115 m and 120 m is found in the Halifax-Sable Island map area. It relates to an old shoreline developed during a Late Pleistocene lowering of sea level about 15,000 to 19,000 years B.P.

Sediment distribution patterns indicate that the old shoreline also crossed the Banquereau-Misaine Bank map region. However, the terrace in that locale is practically absent. Terrace features may have been obliterated by slumping down the steep slopes found across the region.

V.A.11
Marlowe 1967

Core and dredge samples, and echo sounding records were obtained from the continental slope in an area located east and southeast of Sable Island. The composition of cores obtained from the area suggests that some submarine sliding or slumping has occurred.

V.A.12
O'Leary 1986

A large compound slide is located between Munson and Nygren canyons below the 1900-m depth on the continental slope of Georges Bank. It is flanked by displaced and disrupted strata for about 20 km laterally, and at least 35 km downslope. Similarly disrupted sediments are common along the lower slope off Georges Bank.

The Munson-Nygren slide is genetically unrelated to adjacent canyons, and may postdate Munson Canyon. Failure is not believed to have resulted from progressive depositional loading.

Certain features of the slide resemble those seen on the Laurentian Rise, and attributed to the 1929 Grand Banks earthquake. The Munson-Nygren slide may also be related to a large recent (Late Pleistocene?) earthquake.

V.A.13
Piper and Normark 1982a

The 1929 Grand Banks earthquake is believed to have triggered large slumps, and also a turbidity current that broke submarine cables crossing the Laurentian Fan (see V.A.6). Debris flow deposits over 100 m in thickness, and turbidite deposits have been detected on the Laurentian Fan and Sohm Abyssal Plain below the 1929 epicentre.

The 1929 event was not isolated, as evidenced by seismic, coring and other data obtained in 1978 and 1981. Data confirm that sediment slumping is common within 100 km of the 1929 epicentre.

One particularly major event occurred in the Late Holocene (about 100,000 years). It is thought to be equivalent in scale and extent to the 1929 earthquake. The event affected the continental slope, Laurentian Fan and Sohm Abyssal Plain, causing widespread slumping and turbidity currents. Earlier episodes of major slumping and debris flowage also occurred. Late Pleistocene turbidites are ubiquitous, and may have been formed by seismically-triggered slumping.

Grand Banks-scale earthquakes probably have a recurrence interval of hundreds of thousands of years, but significant lesser events are considerably more frequent.

V.A.14
Piper and Normark 1982b

Several authors have attributed disturbed topography on the upper Laurentian Fan to giant slump blocks released by the 1929 Grand Banks earthquake. (Heezen and Ewing 1952; Heezen and Drake 1964; and Emery et al. 1970 describe slump blocks, turbidity currents and submarine landslides associated with the 1929 earthquake.)

Piper and Normark, however, conducted more recent detailed seismic surveys that uncovered no evidence of large slumps in the study area. Slump-like masses were observed, but appeared in depositional continuity with autochthonous sediments. Surfaces previously interpreted as slide planes are either facies changes, or the result of valley wall erosion.

A few small slump blocks of relatively consolidated material were found on the uppermost Fan. Also, a major slump scar has been reported as lying immediately east of the survey area (D.G. Roberts, pers. comm. in Piper and Normark 1982b). Roberts relates the scar to slumping that followed the 1929 earthquake.

V.A.15
Piper and Sparkes 1987

A detailed survey was made of one small area on the Scotian Slope at 63°20'W. Features interpreted by Hill (1983 and 1984) as being allochthonous blocks preserved within a slide debris mass are shown instead to be autochthonous material stratigraphically continuous with the seabed (see V.A.7).

Sediment failure and mass movement is believed to be less extensive than inferred. Hill's slide blocks are re-interpreted by Piper and Sparkes as erosional features.

The area, however, has undergone some widespread surficial sediment deformation. Late Tertiary and Early Quaternary sediments are folded and, around 1200 m below water surface, form an elongate zone of shale diapirs. Folding may be related to slumping or intraformational deformation. Strata deposited 20,000 years B.P. show local failure.

V.A.16
Piper et al. 1985a

A 50 km by 50 km area on the Scotian Slope just west of Verrill Canyon was surveyed using sidescan sonar, high resolution seismic reflection profiles and piston cores. The site has a gradient of approximately 2.5°, and is crossed by two small valleys that are 1 km wide and 100 m deep.

The seabed shows scars caused by surficial slides that removed 10 m to 20 m of sediment. Two zones of disturbed sediments are detected between the 600 m and the 1800 m isobaths. The disturbed zones appear to be rotational slide deposits, with true debris flows only at their distal limits. Erosional depressions observed further downslope may have resulted from turbidity currents associated with the debris flows.

Such widespread sediment failure on relatively low slopes probably resulted from a large earthquake. Faunal and floral evidence from cores date the seismic event as having occurred between 5000 and 12,000 years B.P.

(This paper is a composite, updated version of Piper and Wilson 1983; and Piper et al. 1983).

V.A.17
Piper et al. 1985b

The Laurentian Fan is located off the eastern continental shelf, between the rifted continental margin of Nova Scotia and the inactive margin of the southwest Grand Banks. It contains two major erosion valleys that developed in the Late Quaternary, and also encompasses the epicentre of the 1929 Grand Banks earthquake.

Much of the Late Quaternary sediment on the Fan derives from slumping of glaciomarine sediment off the upper slope. Some slumping probably is seismically induced: a zone of recent seismicity extends east-west across the Laurentian Channel and eastward. Turbidites were more frequent during glacial periods than at present, suggesting that Quaternary slumping might also have resulted in part from rapid sediment overload.

Within 100 km of the epicentre, surface strata are highly discontinuous, reflecting widespread surface slumping and sliding within the zone. A large debris flow lies just downslope from the epicentre. As well, slide blocks measuring up to hundreds of metres in dimension are present, although rare.

(This paper summarizes several of the other reports on the Laurentian Channel and Fan mentioned in the present chapter.)

V.A.18
Stanley and Silverberg 1969

The Sable Island Bank lies on the outer Nova Scotian Shelf. The continental shelf southeast of the Bank is scalloped by many large depressions one to five (or more) miles across, and 550 m to 732 m in relief. Bottom and subbottom profiles reveal large slide blocks on the lower slope and rise in the area, suggesting that mass gravity processes may have caused the depressions.

Gravity slides probably occurred throughout the Tertiary, but increased in scale and rate during the Pleistocene. Cores penetrating Pleistocene and Holocene glaciomarine sediments indicate that mass movements continue up to the present time. Slumping could be triggered by depositional conditions, or by deep seated tectonism.

V.A.19
Stow 1975

Sediments obtained from Facies D of the Laurentian Fan channel deposits show a distinct overall grading visible in the upper metre or so of cores. These topmost graded sequences may have been deposited from a turbidity current initiated by the 1929 Grand Banks earthquake.

V.A.20
Uchupi and Austin 1979

Stratigraphy and structure of the Laurentian Cone was analysed using seismic reflection profiles, geophysical and well data.

The morphology of the Laurentian Cone seems related primarily to turbidity current activity. Slump structures are less common than previously thought. Turbidity currents following the 1929 Grand Banks earthquake probably had more influence on sedimentary deposition in the region than did the slumping which caused the currents.

Sediment continues to move down-cone in response to sporadic seismic activity.

Bay of Fundy

V.A.21
C. Amos (pers. comm.)

Seismic reflection work was done in Chignecto Bay at the head of the Bay of Fundy. Profiles detected highly contorted sediments, including a large submarine slump that measures about 3 km to 4 km long and 1 km wide.

The slump is situated off Cape Enrage, along an extension of the Cobequid Fault. Failure is estimated to have occurred between 3000 and 4000 years B.P., suggesting that some recent movement may have occurred along the fault.

V.A.22
Dalrymple 1979

Soft sediment deformation features are common in intertidal sand bodies in Cobequid Bay, Bay of Fundy. These slump-like features are one to three cubic metres in area, and occur when liquified sand slumps and flows down the megaripple stoss side.

Field and laboratory evidence strongly indicate that liquifaction is triggered, not by earthquake shock, as has been suggested, but rather by waves 10 cm to 30 cm high, breaking against the megaripple lee faces. Wave induced soft sediment liquifaction should be expected wherever freshly deposited, crossbedded sands are exposed to wave action.

V.A.23
Dalrymple et al. 1982

A fossil community of subtidal oysters was discovered near Grand Pré in Nova Scotia. The oysters immediately overlie a salt marsh community, and are perfectly preserved, implying a sudden transition from a salt marsh to a subtidal environment through rising sea level or bottom subsidence.

The oysters are dated at about 3700 years B.P. Coincidentally, a large submarine slump of comparable age (see V.A.21) has been detected by seismic reflection at Chignecto Bay. Some catastrophic event such as rapid bottom subsidence, perhaps triggered by seismicity, may have caused both the slumping and oyster deaths.

B. RECENT FAULTING AND REGIONAL UPLIFT/SUBSIDENCE

Eastern Offshore

V.B.1
Atlantic Geoscience Centre 1985

The following quote is from a technical review of the Hibernia Development Project's environment impact statement.

> "The Environmental Impact Statement shows faults bounding the Hibernia structure that cut Tertiary rocks. While growth faults in non-indurated strata cannot generate even moderate earthquakes, proprietory deep seismic data available at Atlantic Geoscience Centre [in Bedford, Nova Scotia] show the boundary faults extending down to about 15 km; at such depths the faults could easily be seismogenic" (p. 4).

V.B.2
Durling and Fader 1986

A seismic risk assessment was carried out in the eastern Scotian Shelf and Laurentian Channel area, preparatory to Venture hydrocarbon development near Sable Island. The authors analysed over 12,000 km of airgun seismic reflection profiles and Huntec DTS high resolution seismic reflection profiles.

Considerable tectonic deformation was detected in the study area. Forty-two faults intersect Tertiary, Cretaceous or older bedrock, with the largest measured throw being 35 m. Only two faults clearly offset Quaternary sediments. Relationships between bedrock and surficial faulting could not be determined, due to insufficient data.

Both Quaternary faults occur on slopes greater than 6°. One is located near Artimon Bank (44°50'N, 58°40'W) in an area of high relief. It offsets the Emerald Silt Formation, and has a throw of about one metre.

The second recent fault lies at 45°14'N, 57°52'W. It occurs in lift-off moraines. Interpretation of faults in such sediments is questionable.

The apparent paucity of Quaternary faulting may possibly be misleading. The seismic source (an airgun) used to obtain most of the data creates a pulse that renders the first 10 m to 15 m of geology unresolvable. Because the most recent Quaternary sediments in many areas are thinner than 15 m, their structure can not be accurately determined.

V.B.3
Finley 1978

Offshore sedimentary structures were surveyed southwest of Nova Scotia using seismic reflection profiling. Both slumping and faulting were detected.

Several diapiric belts were discerned on the middle to lower continental slope, and continental rise. In places, upward movement of the diapirs has deformed the overlying strata with normal faults. Some diapirs apparently are still migrating, as the faults can be traced right up to surface.

Finley believes the diapirs are composed of salt. Keen et al. 1975, however, consider them as part of a mudstone ridge complex (see V.B.6).

V.B.4
Jansa and Wade 1975

During the Late Cretaceous or Early Tertiary, rapid regional tilting affected the Scotian Shelf area. The hinge zone apparently lay just north of Sable Island (Wade 1981). Faults also developed at this time, including numerous growth faults that formed parallel to the shelf edge. Both types of deformation were related largely to salt diapirism and the associated plastic seaward migration of sediments.

Salt domes have, in places, apparently pierced as much as 30,000 feet of sediments. Tertiary and Quaternary sediments show locally thick accumulations adjacent to diapirs, indicating that at least some diapiric movement has occurred relatively recently.

V.B.5
Keen 1978

Biostratigraphic data from 11 deep exploratory wells off Nova Scotia (and from wells off Labrador and Newfoundland) were examined to determine subsidence histories of the Labrador and Nova Scotia rifted continental margins.

When subsidence rates were 'corrected' to remove the effects of sediment loading and eustatic sea level changes, a significant subsidence component remained - namely that caused by thermal contraction of the lithosphere, or other deep seated tectonic process.

V.B.6
Keen et al. 1975

In 1972 and 1973, seismic refraction measurements were made on the continental margin off Nova Scotia to investigate the transition region between oceanic and continental crust. Transit lines also intersected what Keen et al. interpret as a sedimentary ridge complex comprising diapiric pre-Late Cretaceous mudstones.

Emery et al. (1970) suggested that the complex formed during initial rifting of the continents. Keen et al., however, attribute it to sediment migration caused by differential downwarping of crustal rocks. Seismic reflection measurements show that the complex intrudes Middle Tertiary to Pleistocene sediments, thus dating it as a relatively recent feature.

V.B.7
King and MacLean 1976
(With additional notes from King and MacLean 1970)

The Orpheus Basin extends from Chedabucto Bay in Nova Scotia seaward across the northeast the Scotian Shelf, and into the Laurentian Channel. It is fault bound, filled with low density sediments, and is associated with a major negative gravity anomaly.

Cretaceous beds along the northern boundary of the Orpheus Basin are faulted and folded. Deformation may have been Tertiary or earlier.

Cretaceous strata within the basin are faulted and folded due to salt tectonism, and to movement along an eastward extension of the Cobequid-Chedabucto Fault System. Final major adjustments along the system probably occurred during the Late Cretaceous or Early Tertiary, as Tertiary strata are not folded. Regional tilting also affected the area, possibly as late as the Late Pliocene.

The Cobequid-Chedabucto Fault System crosses Nova Scotia from the Bay of Fundy to Chedabucto Bay and perhaps continues eastward along the south side of the Orpheus anomaly toward the continental slope. Earthquake epicentres plot near where the proposed trace crosses the continental slope. Seismic events could be related to minor adjustments along the old fracture system.

V.B.8
Mann 1977

Biostratigraphic data from twenty wells reveals that subsidence rates on the Scotian Basin have decreased exponentially with time from the Jurassic to the present.

Subsidence proceeded rapidly during the early development of the basin from the Jurassic to Middle Cretaceous. Rates were about 1 cm to 2.5 cm per thousand years (*Keen* 1973). They slowed down gradually, then experienced a major upsurge during the Early to Middle Tertiary, perhaps due to a local tilting of the continental shelf edge. Subsidence and sedimentation rates decreased in the Middle to Late Tertiary.

Subsidence is ascribed to a combination of several phenomena. The major components are thermal contraction and sediment loading. Changes in paleobathymetry and sedimentation rates are less significant factors.

V.B.9
Smith 1973

Orphan Knoll is a continental plate remnant located in deep water northeast of Newfoundland. Sedimentologic and tectonic analyses of the Orphan Knoll fragment indicate that it began to separate from North America in the earliest Middle Cretaceous, but did not sink until the Early Tertiary.

V.B.10
Swift 1987

A diapir province measuring 40 km to 110 km wide lies on the outer continental margin off Nova Scotia. In a study area located between 61°W and 64°W, closely spaced diapiric stocks of beween 5 km and 10 km in diameter appear to be rooted in deep linear salt ridges that are 70 km to 120 km long. Fault deformation above these stocks extends up to the sea floor, indicating significant Quaternary activity.

V.B.11
Webb 1973

Shallow seismic traverses were run across the western Grand Banks area near the Tors Cove uplift. Structures detected in the vicinity indicate that some salt diastrophism occurred as recently as Late Tertiary to Quaternary times.

Bay of Fundy

V.B.12
Paterson and Jagodits 1966

The Minas Passage Scour Trench is an apparently erosional feature that drops from the 100-feet level down to depths of 300 feet and locally 450 feet. The deepest part of the scour trench is believed to mark the location of a major fault.

C. POCKMARKS

Eastern Offshore

V.C.1
Josenhans et al. 1978

Pockmarks are cone shaped depressions that occur in unconsolidated fine sediments on the seabed. They are generally considered to be formed by gas ascending from underlying sediments.

Pockmarks have been found in several basin areas of the Scotian Shelf. Their size ranges from 15 m to 45 m in diameter and 5 m to 10 m in depth.

Active pockmarks apparently exist in the North Sea and Gulf of Mexico. The Scotian Shelf features, however, seem to be relict.

V.C.2
Jacques/McLelland Geosciences Inc. 1982

Pockmarks are erosional features formed by fluid expulsion. The fluid may be either gas or water. Pockmarks could be hazardous to overlying structures (e.g. oil rigs) if they form catastrophically through high pressure emissions.

The Scotian Shelf pockmarks probably resulted from low pressure emissions. However, seismic shaking from earthquake shocks could allow excess pore pressures to build up, causing fluids to escape at greater than normal pressures.

V.C.3
Fader et al. 1982

Pockmark-like depressions were found at several sites in the Laurentian Channel/western Grand Banks area. Some occurred in LaHave Clay in the deepest part of Cabot Strait between Cape Breton Island and Newfoundland. Also, gas-charged zones were detected within LaHave Clay in the fiords and inner bays along the south coast of Newfoundland.

PART II. MEASURING NEOTECTONISM: Direct and Indirect Measurements of Neotectonism in the Maritime Provinces

CHAPTER VI: DIRECT MEASUREMENTS OF NEOTECTONISM

A: GEODETIC SURVEYS

New Brunswick and Nova Scotia

VI.A.1
Carrera 1984

Two generations of geodetic levelling were performed in the Maritime Provinces, one between 1909 and 1923, and the other between 1952 and 1978. Results indicate that significant and anomalous misclosures exist in the height of lines connecting various locations in Nova Scotia, New Brunswick and the Gaspé region.

There appears to be a significant relationship between levelling lines delineating the misclosure loops, and epicentres of seismic activity. Carrera writes: "it is not adventurous...to suggest that some of the large misclosures...may very well be a consequence of VCM [vertical crustal movement] discontinuous in time and space" (p. 125). Seismic activity could be related to differential crustal movement occurring near the 'boundaries' between the levelled areas.

VI.A.2
Grant 1980a

Geodetic relevelling across the Maritimes shows that, between the time periods 1909-1915 and 1968-1971, the southern part has sunk 20 cm to 30 cm relative to the north. The Sackville area in New Brunswick subsided about 12 cm more than did the Fredericton area, and 17 cm more than did the Edmundston area.

VI.A.3
M. Pedroza (pers. comm.)

A geodetic survey is presently underway in the vicinity of The Rocks, Fundy National Park, New Brunswick. Twenty-six object points were emplaced along the coast, and monitored by twelve geodetic stations.

Measurements collected between June and September 1987 revealed no significant movement. These results, however, are only preliminary, as the survey is in its initial stages.

VI.A.4
Vaniček 1975

Vertical crustal movements in Nova Scotia were estimated from geodetic relevelling of one hundred points scattered about the province, together with sparse tidal gauge information (see VI.B.1). Subsidence rates in the Minas Basin area are significantly faster than those elsewhere around the coast.

VI.A.5
Vaniček 1976

Vertical crustal movements in Nova Scotia were assessed using geodetic relevelling of 308 points from across the province, together with data from 8 tidal gauges (see VI.B.2). Results confirm that a belt of faster subsidence trends west-northwest across the eastern end of the Bay of Fundy. They also suggest (but do not confirm) a region of rapid uplift in northeast New Brunswick and the Gaspé Peninsula.

VI.A.6
Vaniček and Nagy 1981

Some 5046 relevelling segments plus water and tidal gauge data were used to create the first vertical movement map of Canada. In the Maritimes, the earlier-implied centre of uplift in northeast

New Brunswick (see VI.A.4) is relocated further east nearer Anticosti Island.

Maine

VI.A.7
Anderson et al. 1984

This report summarizes unpublished results from five years of multi-disciplinary investigations into the potential relationship between seismicity, sea level rise and crustal movement in Maine. Results indicate that parts of the Maine coast are subsiding at the rate of 9 mm per year, and that subsidence is associated with seismic activity. Additional evidence for subsidence comes from archaeological, historical, tidal gauge and geomorphological observations.

VI.A.8
Brown 1978

A detailed profile of apparent vertical crustal movements was produced from precise levelling data obtained by the National Geodetic Survey in the United States. The profile correlates weakly with topographic, gravity and seismic data. However, there is a strong regional correlation between vertical movement, and tectonic and geomorphic features. It is therefore believed that the observed vertical movements are tectonically related, at least in the locations in which the correlation exists.

VI.A.9
Reilinger 1987

An uncorrected systematic error was perpetuated in the critical geodetic survey used to estimate rapid contemporary crustal subsidence in Maine as being 9 mm per year (see VI.A.7 and VI.A.11). Re-analysis of levelling observations indicates a slower subsidence rate of about 1 mm to 2 mm per year. The rate is more in keeping with information derived from tidal gauge data and other sea level indicators.

VI.A.10
Tyler et al. 1979

Comparisons of vertical levelling data from the U.S. Coast and Geodetic Survey indicate that between 1942 and 1966, the differential downwarping of the Maine coast reached as high as 175 mm.

VI.A.11
Tyler and Ladd 1980

Vertical crustal motion in Maine was studied through analyses of repeated first order levelling data. Results show substantial changes in observed height differences within the approximately fifty years of records.

Easternmost Maine is subsiding at a rate of up to 9 mm per year. Southern Maine is subsiding more slowly, at up to 3 mm per year. Analyses of eustatic sea level change, salt marsh growth, and inundated historic structures support the hypothesis of subsidence.

(See VI.A.9 for discussion of these results.)

VI.A.12
Tyler and Leick 1985

In spring 1982, an engineering firm informed the Maine Geological Survey that they suspected horizontal crustal motion near the Grand Falls Dam on the St. Croix River. The dam site had been suffering foundation problems. Furthermore, a re-survey of International Boundary Commission stations indicated movement on the order of 11 feet since about 1900. The Survey decided to undertake a geodetic investigation of the area.

Only one single triagulation study was performed using Macro satellite receivers. However, results did suggest the strong possibility of significant crustal motion.

B: TIDAL GAUGE DATA

New Brunswick and Nova Scotia

VI.B.1
Vaniček 1975

Relative sea level data from three tidal gauge records (one each in Halifax, Saint John and Charlottetown) were recalculated to supply information on vertical crustal movements in Nova Scotia. After subtracting the eustatic water rise of 10 cm per century, the following absolute crustal subsidence rates were obtained:

Halifax:	28.7 ± 1.5 cm/century
Charlottetown:	19.6 ± 3.4 cm/century
Saint John:	29.0 ± 2.4 cm/century

VI.B.2
Vaniček 1976

Relative sea level data were obtained from eight tide gauge stations across the Maritimes. The figures were recalculated, taking into account standard deviation and eustatic water rise, to produce the following crustal velocities of uplift or subsidence.

Saint John	-29.2 cm/century
Yarmouth	-19.9 cm/century
Boutilier	-44.6 cm/century
Halifax	-30.4 cm/century
Pictou	-26.1 cm/century
Charlottetown	-24.1 cm/century
Point Sapin	+113.2 cm/century
Father's Point	+7.9 cm/century

Maine

VI.B.3
Reilinger 1987

Tidal gauge records from Eastport, Maine between 1930 and 1985 show a mean relative sea level rise of 2.8 mm per year. Subtracting the eustatic sea level rise (1.0 mm to 1.5 mm per year) gives an absolute subsidence rate at Eastport of about 1.3 to 1.8 mm per year. This figure supports recent relevelling data.

C: GRAVITY AND TILTMETER OBSERVATIONS

New Brunswick

VI.C.1
Burke et al. 1982

The Devonian North Pole pluton lies in the epicentral region of the 1982 Miramichi earthquakes, and has intruded deformed Cambro-Ordovician metamorphic rocks. A large gravity low coincides with the pluton, reflecting a density contrast between it and the country rocks.

Initial thickness estimates from gravity anomalies indicate that the relatively shallow Miramichi earthquakes are confined to the plutonic body. This may reflect the fact that the brittle plutonic rocks are weaker than the surrounding, stronger metamorphic country rocks, and would respond differentially when exposed to the same stress regime.

VI.C.2
Lambert and Beaumont 1977

Six nanogravity surveys performed in Cap Pelé, New Brunswick and York Point, Prince Edward Island determined how gravity changes are affected by seasonal groundwater fluctuations.

Normal groundwater variations may obscure gravity changes associated with tectonic movements and earthquake precursory effects. When normal variations are known or are insignificant, however, tectonic gravity changes as small as 2 μgal to 3 μgal may be detected at 90 per cent confidence. This corresponds to a 'free air' elevation change of about 1 cm.

VI.C.3
Pagiatakis and Vanicek 1985

About two years' worth of bedrock and atmospheric temperatures, air pressure and water table level data were used to study the response of tilt and gravity data to these phenomena. Analyses showed that atmospheric effects, groundwater level changes and ocean tide loading significantly affected the tilt and gravity records as measured from an earth tide station in Fredericton.

Nova Scotia

VI.C.4
Beaumont and Boutilier 1978

A re-examination of tilt observations from Nova Scotia confirms that the crust beneath the province is transitional between oceanic and thickened continental crust. It thus deforms more easily than most other crustal types.

VI.C.5
Beaumont and Quinlan 1977

A relationship exists between an earthquake's timing, and the maximum of the solid earth tide shearing stress on the active fault plane. A Fundy tidal power project would cause an increase in pore fluid pressure and load induced stress on crust beneath the Bay of Fundy.

Under certain circumstances, increased pore pressure amplifying the earth tide stresses could trigger earthquakes, but only if the crust is under critical tectonic stress. It is unknown whether this description applies to the Bay of Fundy region.

VI.C.6
Lambert 1969

An eight month series of tiltmeter measurements were made in an abandoned mine at Rawdon Centre, Nova Scotia to study the earth's tilt response to diurnal and semi-diurnal constituents of the ocean tide.

Results indicate that (1) the Bay of Fundy tilt fits a simple two layer elastic model having rigidities compatible with seismic models for the area, and (2) tilts caused by the more extensive tides outside the Bay of Fundy are not compatible with any laterally homogenous elastic model.

The anomalous open ocean tilting may reflect a large scale continental structure that is responding coherently to tidal loading in the Gulf of St. Lawrence and on the continental shelf.

VI.C.7
Rouleau 1984

Two tiltmeters were installed in a shallow vault at Shelbourne, Nova Scotia. Tidal analysis shows that, for the principal semidiurnal constituent M2, the west component of the observed deflection differs by 12 per cent from the theoretical value. This discrepancy increases westward, suggesting the influence of lateral heterogeneities beneath the Gulf of Maine.

VI.C.8
Stevens 1977

The Nova Scotia crust is 10 km thinner south of the Cobequid-Chedabucto fault system than north of it. It also is 13 km thinner than crust in New Brunswick, and shows a pronounced negative gravity anomaly. As well, seismic velocities in the south block are lower than in blocks further north and west; the deep seismic zone is totally absent.

Differential isostatic unloading of the dissimilar crustal blocks following glaciation may account for minor earthquakes in the region. Triggering also could arise from the blocks' differential response to diurnal earth tides.

VI.C.9
P. Vaníček (pers. comm.)

A recently published map - UNB December 1986 Geoid Referred to GR 580 (1:7.5 million, compiled by André Mainville) - shows significant disturbances in the gravity fields across upper Nova Scotia. One disturbed zone appears to overlie the Chedabucto-Cobequid Fault System. These disturbances are symptomatic of density contrasts that in turn could signify differential movement of the crust.

Maine

VI.C.10
Gates 1978

A pronounced Bouguer gravity high of +35 mgals along coastal area of Machias-Eastport reveals underlying mafic rock. A gravity low of −30 mgals coincides with granite plutons 25 km inland to the northwest.

Minor isostatic adjustments to this difference of mass within a short distance could cause crustal movement along nearby faults. It could account for historic and current seismic activity in the area.

CHAPTER VII: INDIRECT MEASUREMENTS OF NEOTECTONISM

A. IN SITU MEASUREMENTS

New Brunswick

VII.A.1
Cox 1983

Oil well breakout data from the Gaspé and Maritime Provinces indicate regional east-west to northeast-southwest compression.

VII.A.2
J. Gilby (pers. comm.)

Golder Associates made several in situ stress measurements at coal mines on Cape Breton Island. Results are given below. All readings are oriented according to true north.

Lingin Mine: (tested in 1986 using overcoring)

Principal Stress	Azimuth/Dip
S1 = 33.8 MPa	088°/04°
S2 = 14.5 MPa	355°/35°
S3 = 12.2 MPa	004°/−55°

Prince Mine: (tested in 1985 using overcoring and hydrofracturing)

Principal Stress	Azimuth/Dip
S1 = 11.8 MPa (O)	263°/14°
= 13.2 MPa (H)	
S2 = 09.5 MPa (O)	-7.8°/05°
= 10-12 MPa (H)	
S3 = 05.1 MPa (O)	64°/-7.5°
= 5.4-5.9 MPa (H)	

VII.A.3
J. Gilby (pers. comm.)

In 1984, Golder Associates recorded in situ stress measurements for the No. 26 Colliery of the Sydney coalfield, Cape Breton. Overcoring holes were located about 300 m from the boundary of current mine development, at the north end of the main deeps.

Magnitudes and directions of the principal stresses were calculated from five biaxial tests. Azimuths are referenced to the mine's grid coordinate system, which is 1° east.

Principal Stress	Azimuth/Dip
S1 = 26.30 MPa	270°/-25°
S2 = 24.05 MPa	009°/-13°
S3 = 23.20 MPa	278°/ 64°

VII.A.4
McKay et al. 1985

Stress data obtained by Golder Associates from a depth of 1 km in the Brunswick Mining and Smelting No. 12 Mine in Bathurst show the following values. (Data was obtained from a letter written to J. Adams by C. Pagel.)

Principal Stress	Azimuth
S1 = 55 MPa	303°
S2 = 37 MPa	033°
S3 = 23 MPa	196°

VII.A.5
McKay et al. 1985

In situ rock stress measurements were made in six separate boreholes drilled down about 30.5 m at the Miramichi earthquake site in the summer of 1984. Measurements in five of the six borings give trends ranging from 055° to 095° for the principal secondary stress in the horizontal plane. Stress measurements directions for Borehole 4 average 274°. P stresses summarized from all six boreholes range from -4.89 MPa to 22.74 MPa.

Only results from Borehole 4 support the presumed existence of east-west horizontal compressive stresses being active in the area. Several borehole stress measurements produced tensional stresses in at least one component direction.

According to Adams et al. (1984), the wide scatter in stress magnitude and direction results indicates that the near surface is partly decoupled from regional stresses. McKay et al. suggest that the relatively relaxed post-earthquake conditions would allow local structural features to dominate post-quake stress fields in the rock.

Nova Scotia

VII.A.6
Bell and Podrouzek 1985

Principal stress magnitudes from depths between 750 m and 6000 m have been estimated from information gathered in Scotian Shelf exploration wells. Wellbore breakout azimuths from 38 wells indicate that the region is presently subjected to anisotropic horizontal stresses. The larger horizontal principal stress trends northeast-southwest, and the smaller horizontal principal stress trends at right angles to this direction.

Tertiary and earlier growth faulting suggest that local extensional regimes have existed periodically on the Scotian Shelf during its depositional history.

VII.A.7
Ervine and Bell 1987

Stress magnitudes were estimated for 44 depth intervals in four wells drilled over the Venture structure on the Scotian Shelf. The maximum principal stress is horizontal below 815 m. The minimum principal stress is horizontal to depths of about 6000 m. Thus, a strike-slip potential conjugate fracture regime exists between 815 m and approximately 6000 m, perhaps passing downward into an area in which preferred fractures would be subhorizontal.

As the 6000 m depth is approached, formation-fluid pressures approach lithostatic levels. The stress threshold for deformation or fault movement is very small at that depth. If minimum principal stresses are indeed vertical below about 6000 m, subhorizontal offsets along faults could easily be generated.

VII.A.8
Plumb and Cox 1987

Borehole elongations observed in 25 wells to depths of about 2 km suggest that eastern Canada is being compressed moderately in a northeast-southwest direction, as a result of subcrustal drag due to westward plate drift. Average maximum horizontal stress directions are 54° ± 7°.

Maine

VII.A.9
Lee et al. 1979

Overcoring tests were performed at three sites in granite and gneiss in the Mount Waldo area, Maine. The average maximum horizontal stresses ranged from 2.29 MPa to 9.49 MPa. Azimuth readings ranged from 4.5° to 60°.

B: MICROSTRUCTURES

VII.B.1
M. Lodin (pers. comm.)

Granite, aplite and mylonitic zone samples were collected from outcrops located close to a north-south lineament near the Miramichi epicentral area. The lineament had been detected earlier from composite analyses of satellite imagery, aerial photographic, aeromagnetic, topographic and VLF data.

Microstructural analyses of six samples reveal both healed and fresh fractures. Very preliminary results suggest a primary fracture orientation of 125° to 140°, with healed fractures being marginally more plentiful than fresh ones. A second dominant orientation occurs at 05° to 20°. In this field, fresh cracks exceed the healed ones.

VII.B.2
Mawer and Williams 1985

The North Pole granite crops out at the epicentre of the 1982 Miramichi earthquake. Granite specimens collected from the site show a distinctive assemblage of microstructures.

The microstructures are interpreted as having resulted from episodic and extensive fluid-assisted microfracturing, followed by fracture healing. The unhealed fractures may be tensile features. One possible trigger for each fracturing episode is paleoseismic activity that continues to the present day.

VII.B.3
O'Neill 1985

Granodiorite samples taken from the 1982 Miramichi epicentral area reveal a parallel network of tensile fractures. The microfractures are believed to have formed in response to a stress regime whose maximum principal stress orientation is horizontal and trends east-west, and whose minimum principal stress is vertical.

PART III. EXPERIENCING NEOTECTONISM: Historical and Current Seismicity in the Maritime Provinces

CHAPTER VIII: HISTORICAL SEISMICITY

A: COMPILATIONS OF HISTORICAL SEISMIC EVENTS

New Brunswick

VIII.A.1
Burke et al. 1985

Burke and others compiled reports of seismicity in northern and eastern New Brunswick between 1867 and 1943. Information sources were old newspapers and other archival sources.

VIII.A.2
Burke and Comeau (in press)

This second archival study of historical seismicity in New Brunswick concentrates on the Passamaquoddy Bay area. It covers the years between 1900 and 1961.

VIII.A.3
Kain 1898

Kain lists recorded earthquakes in New Brunswick from February 1663 to January 1898.

VIII.A.4
Kain 1904

Kain's second list records earthquakes in New Brunswick and covers the time period from August 1898 to March 1904.

VIII.A.5
Leblanc and Burke 1985

Earthquakes that occurred in 1817, 1855, 1869 and 1904 may be the four largest seismic events affecting Maine and New Brunswick in the 165 years before the 1982 Miramichi earthquake.

The 1817 and 1904 events, and most probably the 1869 event, are believed to have originated in the Passamaquoddy Bay area. The 1855 event can be clearly placed in the Moncton-Dorchester region, southwest New Brunswick.

Magnitude estimates for the 1869 and 1904 earthquakes are substantially higher than estimates presently listed for the events in the Canadian Earthquake Epicentre File. The similar intensity patterns of the two events suggest a common source zone. Felt data for the 9 January 1982 Miramichi earthquake (known to be of magnitude mb = 5.7) and for the 1869 and 1904 events also are similar, suggesting a common magnitude range for all three events.

Nova Scotia

VIII.A.6
Adams et al. 1984

Historic records document seismic activity on the eastern offshore perhaps as far back as 1864. (Marine geological evidence suggests events have taken place for thousands of years before that: see Chapter V).

Earthquakes occurred in 1951, 1952, 1975 and 1983, but were not felt on land. By far the largest documented earthquake (Ms 7.2) took place in 1929 on the Grand Banks.

VIII.A.7
Ruffman and Peterson (in press (a))

Although this report deals primarily with historical seismicity of Nova Scotia between 1752 and 1867, it includes references to other Atlantic Region earthquake events. The study records dozens of newly documented earthquakes and several newly documented tsunamis.

VIII.A.8
Ruffman and Peterson (in press (b))

This compilation of newspaper articles documents the felt effects (both cultural and geological) of the 18 November 1929 Grand Banks earthquake. The earthquake affected not just Newfoundland, where the resultant tsunami destroyed property and killed 26 people, but also Nova Scotia and Bermuda.

VIII.A.9
Smith 1962

Smith lists earthquakes recorded from eastern Canada including New Brunswick and Nova Scotia, as well as from Maine, between the years 1534 and 1927.

Maine
(See also New Brunswick entries in this chapter.)

VIII.A.10
Foley et al. 1984

Recent earthquakes in eastern Maine near Passamaquoddy Bay prompted research into historic seismic activity in the region. Examination of archival records revealed frequent earth tremors and sporatic events of stronger seismicity throughout the 111 years covered.

VIII.A.11
Smith and Bridges 1983

This account lists several dozen earthquakes recorded in the Passamaquoddy Bay area between 1663 and 1900.

VIII.A.12
Thompson 1981

Thompson documents six earthquakes recorded in the vicinity of the Norumbega Fault Zone between 1874 and 1938. Their intensities ranged from IV to VII on the Modified Mercalli scale.

B: SEISMOTECTONICS

This section provides selected references equating historical (and current) seismicity with known tectonics for the entire region encompassing the Maritime Provinces and Maine.

VIII.B.1
Adams et al. 1985

Examination of seismograms covering the years 1975 to 1985 has revealed over twenty new offshore earthquakes. About half of these events (plus relocated earlier-known earthquakes including the 1929 Grand Banks earthquake) lie in a definable zone at the mouth of the Laurentian Channel (44.7°N, 56.5°W). The zone trends east-west for about 110 km and is 30 km from north to south.

Smaller earthquakes seem to occur nearer the ends rather than the centre of the zone. They could represent delayed aftershocks, which are releasing stresses concentrated at the ends of an east-west fault that ruptured in 1929.

The Northern Grand Banks demonstrate a higher level of seismic activity than was previously assumed. Seismicity also affects two other offshore locales: along the ocean-continent boundary south of Nova Scotia, and along the Laurentian Fan.

VIII.B.2
Barosh 1978

The Penobscot lineament trends northward for about 300 km through Maine, and may be a branch of the right-lateral strike-slip fault in Penobscot Bay. This fault has shown possible Holocene movement on Sears Island, and might be related to the lineament.

The lineament joints the Norumbega Fault Zone to the northeast. Both Penobscot Bay (Barosh 1979) and the Norumbega Fault Zone (Thompson 1981) are areas of higher seismicity.

VIII.B.3
Barosh 1981a

The Passamaquoddy Bay area on the Maine-New Brunswick border has experienced about fifty earthquakes since 1870. Since a microseismic network was established in the region in 1975, events are being recorded at the rate of about seven per year. Many occur near the north-northeast-trending Oak Bay Fault that cuts the bay; others originate adjacent to the northeast-trending Fundy Fault.

Subsidence has been documented in the region, possibly as a result of minor rifting associated with two graben structures that underlie the Bay of Fundy and Passamaquoddy Bay. The subsidence could be initiating minor fault movement and hence the observed seismicity.

VIII.B.4
Barosh 1981b

Seismicity in the eastern United States and adjacent Canada seems to be related to neotectonic movement from a single stress field created by continued opening of the Atlantic basin. Evidence suggests that seismicity is associated with subsiding embayments and bays on the Cretaceous continental margin, adjacent rising upland areas plus the north- to northwest-trending faults and grabens found inland from the margin.

Most seismic events take place in lowlands along inland edges of embayments, where the crust is believed to be subsiding. The magnitude of past earthquakes apparently relates directly to the size of the embayment they occur in. The only major upland areas of seismicity lie in zones that are apparently rising.

(Barosh (1980) and Barosh (1987) are slightly altered variations of this paper.)

VIII.B.5
Barosh 1985

Major northeast-trending fault zones have been revealed in the northeastern United States by geophysical and LANDSAT data, and detailed geological studies. They can be grouped into long fracture zones, ranging in age from Precambrian to post-Cretaceous. Many younger zones are probably reactivated buried older fracture zones.

Movement along the fracture zones has controlled formation of the northwest-trending Late Cretaceous and Tertiary basins and embayments in the coastal plain deposits. Present day movement, as revealed by earthquakes, tends to occur locally along the fractures. This is particularly evident where they cross northeast-trending belts that are affected by vertical movement.

VIII.B.6
Barosh 1986

An eight-year New England Seismotectonic Study has resulted in the production of an earthquake zonation map for the northeastern United States.

Most earthquakes are associated with northwest-trending faults, along which movement is mainly transcurrent. Some earthquakes occur along north-trending faults that show extensional movement. Relatively few seismic events are seen along northeast-trending faults.

A regional tilt to the north, and any residual effects of glacial rebound, appear not to affect seismicity. Rather, the movements producing seismic events seem related to the continued opening of the North America basin. These movements are controlled by a maximum horizontal compressive stress oriented about north-south.

VIII.B.7
Burke 1984

Earthquakes have been felt or reported in the Maritime Provinces for over two hundred years. Epicentral areas of the more recent events - the Grand Banks, Bay of Fundy, Moncton-Dorchester area (N.B) and Central Highlands (N.B.) - coincide with those of the larger, historic earthquakes. Reactivation along old fault lines, concentration of stress at pluton boundaries, and isostatic rebound all have been hypothesized to cause regional earthquakes.

VIII.B.8
Ebel (in press)

Recent seismicity in Maine generally occurs in the same areas that were active historically, namely east, central, coastal and west Maine. Estimated return times for earthquakes of magnitude 5, 6 and 7 are about 50 years, 350 years and 2600 years respectively in the state.

Earthquakes probably result from reactivation of old zones of weakness in the present tectonic stress field; however, no individual faults or other structural features have yet been confirmed as being seismically active.

VIII.B.9
Gates 1978

Historical records document ten earthquakes in the Machias-Eastport area of Maine within the last century. The earthquakes are roughly aligned along the Oak Bay Fault and its extension into the Bay of Fundy.

VIII.B.10
Hussey 1985

In the Portland district of Maine, several historic earthquake epicentres appear to lie close to the intersections of the Nonesuch River and Flying Point faults. In the Bath area, the April 1979 epicentre lies close to the Phippsburg Fault. This suggests that some faults of the Norumbega system may still be active.

VIII.B.11
Quinlan 1984

Quinlan developed a detailed numerical model of postglacial rebound for eastern Canada, particularly the Arctic. The model predicts variations in uplift as a function of time and space since deglaciation, and can be used to estimate temporal evolution of lithospheric stress following deglaciation.

Based on the model, Quinlin predicts that postglacial rebound is capable of initiating earthquakes of up to 10 MPa, but cannot dictate the method of seismic failure. At best, it can trigger the release of pre-existing stress accumulations that have their origins in other processes.

VIII.B.12
Rast et al. 1979

Three hypotheses have been advanced to explain the historic earthquake pattern in Atlantic Canada: (1) movement on faults (2) association with igneous intrusions, and (3) glacial rebound.

Only one of the five major fault episodes in the area reveals any signs of post-Triassic movement. Small scale vertical faults in Triassic rocks around the Bay of Fundy are oriented parallel to the Chedabucto Fault. The faults' strike-slip displacement suggests a component of movement similar to that along the Chedabucto Fault Zone. Also, disturbed glacial deposits were observed to overlie the Oak Bay Fault on Campobello Island, implying syn- or post-Pleistocene movement (see II.C.4).

Although earthquakes are not associated with igneous intrusions as such, they may be related to channels that led magma to the surface. Repeated movements along these deep conduits is provisionally attributed to cooling of the existing thermal high that underlies Atlantic Canada.

The effects of glacial rebound upon Atlantic Canada earthquakes are considered to be secondary.

VIII.B.13
Wang et al. 1979

An active seismic zone extends along the passive margin of eastern North America from Baffin Island to the Newfoundland Grand Banks. The authors postulate that earthquakes occurring along the shore, continental shelf and slope in this region are induced by deglaciation. Lithospheric flexure following deglaciation may have reactivated old basement faults associated with rifting of the Labrador Sea, Atlantic Ocean and Baffin Bay.

CHAPTER IX : CURRENT SEISMICITY

A. REGIONAL SEISMIC DETECTION

The Maritime Provinces possess seven stations capable of monitoring seismic events. Monitoring capabilities include both regional and ECTN stations.

The three regional stations are located in Halifax, Guysborough and Fredericton. All four ECTN systems are in New Brunswick: at St. George near Passamaquoddy Bay, Caledonian Mountain near Moncton, McKendrick Lake near the Miramichi epicentral area, and Edmundston.

Data recorded by the Canadian seismic stations are published four times annually as Canadian Earthquakes: National Summary. The reports are released by the Seismological Service, Geophysics Division of the Geological Survey of Canada.

Maine has about one dozen seismic stations, all of which are monitored by Weston Observatory of Boston College. Data from the Maine seismic stations (plus stations across northeastern U.S.A. and eastern Canada) are published quarterly as Northeastern U.S. Seismic Network Bulletin of Seismicity of the Northeastern United States. Reports can be obtained from Weston Observatory.

B: FOCAL PLANE MECHANISMS

New Brunswick

IX.B.1
Adams 1987

Adams gives focal mechanism measurements for two earthquakes in New Brunswick. One, near Moncton (latitude 46.00° longitude 64.88°) took place on 23 September 1984. Depth estimate for the shock was 12 km, and the P axis azimuth was 238°. The second seismic event, near Doaktown (latitude 46.54° longitude 66.15°) had a depth estimate of 11 km, and a P axis azimuth of 061°. It occurred on 9 May 1986.

Adams also cites the latitude, longitude and P axis azimuth for the various focal mechanisms, well elongation or borehole data points recorded in Plumb and Cox 1987, McKay et al. 1985, Podrouzek and Bell 1985, Saikia and Herrmann 1985, and Wetmiller et al. 1984.

IX.B.2
Adams and Sharp 1986

Based on the information from thirty derived fault plane solutions and about twenty existing ones, it is concluded that thrust mechanisms dominate eastern Canadian earthquakes down to 20 km. However, P axes reveal a discontinuity in the direction of maximum compression. Above about 9 km, the gently dipping P axes lie in the northeast quadrant; deeper, they appear to possess no consistent orientation.

Possibly, regional horizontal stresses become almost isotropic below 10 km, thus allowing minor local features to disturb the compression direction. For three eastern Canada seismic zones, one of which is the Miramichi area, P axes are rotated about 40° clockwise from the regional trend.

IX.B.3
Adams and Wetmiller 1983

Field surveys measured 265 aftershocks in 1982 following the January 9, January 11 and March 31 Miramichi earthquakes. In east-west cross section, the shocks suggest a 'V' shaped fault plane solution with limbs about 2 km thick. The right angle 'V' steepens towards the surface to produce an angular 'U' shape. Composite first motion studies reveal thrusting on north- to northeast-trending faults controlled by an east-west horizontal regional stress.

IX.B.4
Basham 1986

Digital broad band seismic data and reflectivity-method theoretical P wave modelling provided additional information on focal depths and source orientations for the four principal 1982 Miramichi earthquakes.

Earthquake	Intensity(mb)	Depth	Dip
main shock	5.7	7 km ± 1 km	60° W
first aftershock	5.1	6 km ± 0.5 km: near lower portion of mainshock rupture	-
second aftershock	5.4	6 km ± 0.5 km: ruptured conjugate east-dipping focal plane	50°
third aftershock	5.0	2.5 km: in shallow region of mainshock	-

IX.B.5
Basham et al. 1984

Analyses of the four principal Miramichi earthquakes and aftershocks indicate thrust faulting with the rupture forming a conjugate V-shaped, north-trending structure beginning at a depth of 7 km.

Composite P nodal solutions from smaller aftershocks suggest that both planes steepen towards the surface. However, it is unclear from aftershock distribution whether the ruptures occur on single planes, or on shallow dipping principal faults that splay into steeply dipping faults nearer the surface.

IX.B.6
Burke et al. 1986

An onsite microseismic survey was made of the continuing activity in the 1982 Miramichi earthquake epicentral area. Results suggest that activity may be episodic, with days of few earthquakes being followed by mini-swarms of seismic events. The highest rate of activity is associated with a northeastern block east of the previously established (1982) aftershock zone.

Thrust fault plane parameters were calculated from composite P nodal solutions for this eastern block. They place the plane at a strike of 162° and a dip of 82° west, at depths above 4 km. Below this depth, the plane is estimated to trend 197° and dip 42° west. Tentative solutions for the west limb suggest a plane trending 157° and dipping 55 east. Both solutions support the conjugate pattern of north-trending thrust faults obtained from previous studies.

IX.B.7
Ebel and Vudler 1982

Seismic stations in northern Maine detected three foreshocks prior to the 9 January 1982 Miramichi earthquake: two were about nine hours before, and one was 42 minutes before the main shock. During the first week after the main shock, almost 1000 aftershocks were detected including the large January 11 event.

A small earthquake had been recorded earlier from near the same area on 1 September 1977, but may have originated in a slightly different location.

IX.B.8
Lodin 1984

A detailed analysis was made of remote sensing information for the Miramichi earthquake epicentral area. The study integrated the remote data - NOAA, multi-date LANDSAT MSS and airborne MSS - with conventional geological and geophysical data to produce a digital database for the area.

The NOAA image detected several regional lineaments, two of which had not been previously mapped. The LANDSAT MSS imagery of the epicentral area revealed five north-trending lineaments, also unmapped. As well, it extended the trace of a mapped shear zone.

Microseismic data obtained from onsite readings (see IX.B.6) were plotted onto east-west cross sections of the five detected north-trending lineaments (M. Lodin, pers. comm.). Aftershock source points reveal a significant correlation with two of the five lineaments. Three of the five lineaments were subsequently tested by a ground based VLF survey. All three responded as strong conductors.

IX.B.9
Nguyen and Herrmann 1984

Five earthquakes from eastern North America, including the three January 1982 Miramichi earthquakes, have been analysed using the null-centroid technique to determine surface wave focal mechanism. Results for the mainshocks show nearly horizontal compressive stress with an axis trending east-northeast.

New Brunswick aftershocks also have east-west trending pressure axes, but with a component of oblique motion. Focal mechanism results indicate the events result from high angle thrust faulting, and support P wave first motions.

IX.B.10
Saikia and Herrmann 1985

Waveform modelling was applied to determine the focal mechanisms of four 1982 Miramichi aftershocks. The results produced focal mechanisms and synthetic waveforms that closely resembled the observed aftershock waveforms.

Two groups of focal mechanisms were obtained. Two aftershocks possessed a reverse fault geometry, similar to that of the main event on 9 January 1982. The remaining two aftershocks showed similar components of strike-slip motion on a dipping plane.

IX.B.11
Weichert 1985

Strong motion recorders installed shortly after the January 1982 Miramichi earthquake registered peak acceleration over 50% of gravity at high frequencies close to an M 5.0 aftershock. This is an order of magnitude higher than expected from the reported intensities and from the minimal damage experienced. Peak ground velocities, however, plus the low frequency Fourier components of acceleration, are consistent with accepted ground motion/intensity relations.

IX.B.12
Wetmiller et al. 1984

All eight composite focal mechanisms for the Miramichi aftershocks and the Trouser Lake earthquake have near horizontal, east-west directed P axes, suggesting an east-west compressive strain.

Maine

IX.B.13
Adams 1987

Focal mechanism stress measurements were calculated for an earthquake centred in Maine near Passamaquoddy Bay at latitude 44.895° and longitude 67.331°. The event took place on 19 January 1984. Depth estimate for the shock was 12.1 km, and the P axis azimuth was 180°.

IX.B.14
Foley et al. 1984

Passamaquoddy Bay on the Maine-New Brunswick border is believed to be subsiding at a rate of 9 mm per year. The nearby Oak Bay Fault trends nearly perpendicular to the subsidence axis. Five seismic events in the magnitude 3 to 4 range took place near the border in 1983-1984. They occurred at four separate epicentres, all of which lay west of Passamaquoddy Bay and south of the Oak Bay Fault.

A fault plane solution for the largest event (Mn 3.8) indicates a thrust mechanism striking west-northwest.

CHAPTER X: MISCELLANEOUS INDICATORS OF NEOTECTONISM

A: GROUNDWATER PHENOMENA

New Brunswick

X.A.1
Bailey 1904

At Newcastle in Queens County, New Brunswick, a diamond drill was excavating for coal through the 'millstone grit formation' (probably Carboniferous sandstones). Between 100 feet and 200 feet below surface, the drill suddenly dropped. Upon withdrawal, it was followed by a fountain of water several feet high that continued to 'play' for some months.

Bailey implies the event was not isolated, and cites it as among several instances of differential movements in the sandstone formation. No mention is made of what other (if any) instances exist.

X.A.2
Brinsmead 1983

Inspection of several continuously monitored observation wells across New Brunswick revealed that the January 9, 1982 main earthquake shock affected ground water level.

Water level in a Chatham well (80 km from the epicentre) dropped 150 cm in the five days following the earthquake. Other wells showed a marked flow increase. These opposite reponses suggest that large bedrock blocks may have moved relative to one another, causing the opening of some interblock fractures, and the closing of others. This in turn would cause water levels to drop and rise respectively.

It appears that there were no significant water losses during the level changes; rather, there were local changes in hydraulic head as the water redistributed itself through interconnected fractures.

Water levels returned to normal around April 15, probably as a result of spring runoff. It has been suggested that the gradual recharging of earthquake induced water levels may have triggered the June 16, 1982 event in the Miramichi area (J. Adams, pers. comm.).

X.A.3
McKay et al. 1985

Following a rockburst on 20 May 1984 (see I.C.2) a previously dry fracture began to produce one to two litres of water per minute. It alternately ran dry and flowed throughout the afternoon, as subsequent rockbursts erupted.

X.A.4
Ruffman and Peterson (in press (a))

On 8 February 1855 an earthquake centred in the Moncton-Dorchester area in New Brunswick caused landslides on Granville Mountain in Digby, Nova Scotia. The movement apparently was accompanied by unusual groundwater flow.

Shortly after the event, large quantities of steam were observed on the mountain. A visiting geologist concluded that the steam was condensed vapour created when warm groundwater, discovered flowing from a newly formed hole, hit the cold winter air.

X.A.5
Weston Geophysical Corporation 1983

Logs of boreholes drilled in the 1982 Miramichi epicentral area recorded weathered and fractured bedrock, mantled by 23 feet of extremely weathered till overburden. At 75 feet below surface, groundwater inflow increased in an intensely fractured interval. The hole correlates with a north-south lineament, suggesting that the lineament and fractured zone are related.

B: TSUNAMIS

X.B.1
Poirier 1985

A computer program was designed to simulate wave refraction patterns in the Bay of Fundy, to assess what damage might occur from tsunamis originating at known epicentres.

Results indicate that the bay would be protected to the east by Nova Scotia and to the south by Georges Bank. Any incoming tsunamis theoretically would be reduced to safe amplitudes.

X.B.2
Ruffman 1987

Eight tsunami, six of which were previously unrecognized, have been identified in Atlantic Canada (including Newfoundland). They are cited below:

Date	Places Affected	Comments
1 November 1755	east coast, Nfld	
19 January 1813	Liverpool, N.S.	probable tsunami
18 April 1843	Yarmouth, N.S.	
24 September 1848	east coast, Nfld south Labrador	
27 June 1864	St. Shotts, Nfld	
11 September 1908	Gulf of St. Lawrence northern Cape Breton	
undated May 1914	northern Cape Breton	
18 November 1929	south coast, Nfld Cape Breton, N.S. Country Harbour, N.S. St. Margaret's Bay, N.S.	see VIII.A.8

C: SOUND PHENOMENA

X.C.1
Ganong 1896

Deep booming sounds resembling cannon reports occasionally were heard off the south coast of New Brunswick in several areas including Passamaquoddy Bay; forty miles offshore between Grand Manan Island, the Georges Bank and Mount Desert Rock; and southwest of Kennebecasis. The author attributed the phenomenon to either atmospheric or tectonic disturbances.

X.C.2
McKay et al. 1985

On 2 June 2 1984, individuals working in the Miramichi epicentral area detected an audible boom accompanied by a small tremor. A second boom occurred eleven minutes later, with no detectable vibration. Both events may have been aftershocks of the 1982 earthquake series.

D: ROAD CRACKS

Road cracks caused by seismic events belong to a broader topic that could be entitled 'Response of Cultural Features to Seismic Events'. Damages to masonry, roads, crockery, chimneys etc. encompass some of the Modified Mercalli Intensity Scale (MM) indicators used to determine magnitudes of given events.

Many references in Chapter VIII note minor damage to cultural features. The examples are so numerous as to preclude detailed annotation. Interested readers can examine the original papers.

More significant to neotectonic assessment is the far rarer information on cracks in road and sidewalks. Occasionally, it provides some indication of regional stress regimes.

Nova Scotia

X.D.1
Burke and Comeau (in press)

An earthquake estimated to have its centre around St. Andrews struck southwestern New Brunswick on 30 January 1851. Contemporary newspaper accounts reported that a crack appeared in the earth shortly thereafter, near Friar's Head on Campobello Island. It measured one inch in width and about half a mile in length.

X.D.2
Ruffman and Peterson (in press (b))

The 18 November 1929 Grand Banks earthquake caused cracks to appear in several highways in Sydney, Nova Scotia. The earthquake also damaged bridges and created leaks in the city's water mains.

At Black River, Cape Breton Island, the highway developed large cracks following the earthquake.

Maine

X.D.3
Barosh 1983

Fresh road cracks were observed in Presquile, Maine following the 9 January 1982 Miramichi earthquake. Unusually cold weather at the time may have created tension that aided in forming the cracks. Most observed fractures trended northerly.

E: WARM SPOTS

X.E.1
Ganong 1903

Guides in the Tobique River area, northern New Brunswick, reportedly knew of a small 'hotspot' at Blue Mountain, on which a person could sleep without shelter, even in winter. The ground apparently felt warm to the touch. As Ganong suggested, "the investigator of the legend must go to its solution armed with delicate thermometer."

X.E.2
Ganong 1904

Further to the 1903 'hotspot' report, a reliable guide informed Ganong that the phenomenon indeed existed. The mountain could be reached 'eight miles up on the southwest side of a portage road', and was locally dubbed the Rumbling Mountain, due to thunder-like noises that occasionally emanated from it on clear days.

X.E.3
Jones 1961

A large number of people in the Watson Mountain area in northwest New Brunswick believe that the mountain top remains warm enough year around to prevent snow from blanketing the summit.

BIBLIOGRAPHY

Adams, J. 1987: Canadian crustal stress data - a compilation to 1987. Geological Survey of Canada, Open File Report 1622.

Adams, J. (unpublished report): Preliminary description - bedrock exposed by trenching across the surface projection of the 1982 Miramichi earthquake fault plane.

Adams, J. and Sharp, J. 1986: New eastern Canadian focal mechanisms - what happens to the regional stress field below 10 km? Abstract in Seismological Society of America, Eastern Section, Program and Abstracts, Ottawa '86, October 15-17.

Adams, J. and Wetmiller, R.J. 1983: Conjugate thrust faulting during the Miramichi, New Brunswick earthquake sequence of 1982: its geometry, geological control, surface expression, and mechanism. Earthquake Notes, 54 (1), 84.

Adams, J., Basham, P.W. and Wetmiller, R.J. 1984: Young bedrock cracks and near surface stress changes in the Miramichi, New Brunswick earthquake zone. Earthquake Notes, 55 (3), 9.

Adams, J., Reid, J. and Basham, P.W. 1984: Historical seismicity, 1983 OBS experiment and seismic hazard along the southeastern Canadian margin. Abstract in Joint Programme with Abstracts, 18th Annual Congress, Canadian Meteorological and Oceanographic Society, Dalhousie University, Halifax, Nova Scotia, 29 May-1 June 1984.

Adams, J., Wahlstrom, R. and Anglin, F.M. 1985: Reassessment of historical and recent seismicity along the southeastern Canadian continental margin. Earthquake Notes, 56 (3), 65.

Amos, C.L. 1977: An hypothesis on the evolution of the tides in the Bay of Fundy. Geological Survey of Canada, Paper 77-1B, 47-48.

Amos, C.L. 1978: The post-glacial evolution of the Minas Basin, N.S.: a sedimentological interpretation. Journal of Sedimentary Petrology, 48, 965-982.

Amos, C.L., Buckley, D.E., Daborn, G.R., Dalrymple, R.W., McCann, S.B. and Risk, M.J. 1980: Trip 23, GAC-MAC field trip guidebook, Halifax '80, joint annual meeting of the

Geological Association of Canada and the Mineralogical Association of Canada, 82 pp.

Anderson, W.A., Kelley, J.T., Thompson, W.B. et al. 1984: Crustal warping in coastal Maine. Geology, 12, 677-680.

Anonymous 1983: Evaluation of River Hebert subsidence. Nova Scotia Department of Mines and Energy, Mining Engineering Division, Open File Report 632.

Anonymous 1985: A report and summary of a program to identify and alleviate the hazards posed by abandoned mine openings. Unpublished report, Nova Scotia Department of Mines and Energy, Mining Engineering Division, October 1985, 24 pp.

Anonymous 1988: Mine subsidence in Nova Scotia. Unpublished report, Nova Scotia Department of Mines and Energy, Mining Engineering Division, 10 pp.

Atlantic Geoscience Centre 1985: Technical review of the Hibernia development project, environmental impact statement. Atlantic Geoscience Centre, Earth Physics Branch, Office of Environmental Affairs, August 1, 1985, 5 pp.

Bailey, L.W. 1904: New Brunswick caves. Bulletin of the Natural History Society of New Brunswick, V (XXII), part II, 155-169.

Barosh, P.J. 1978: The Penobscot lineament zone. p. 119-128 in Proceedings of the Third International Conference on Basement Tectonics, ed. D.W. O'Leary and J.L. Earle, Durango, Colorado, U.S.A., May 15-19, 1978.

Barosh, P.J. 1979: Earthquake distribution in space and time in the northeastern United States. p. 1-26 in New England Seismotectonic Study Activities During the Fiscal Year 1978, ed. P.J. Barosh et al., NRC FIN No. B5961.

Barosh, P.J. 1980: Relationship of earthquakes with vertical crustal movements in the eastern United States and adjacent Canada. Earthquake Notes, 51 (3), 10.

Barosh, P.J. 1981a: Seismicity and tectonics of the Passamoquoddy Bay area, Maine and New Brunswick. Abstracts with Programs, Geological Society of America, 13 (3), 122.

Barosh, P.J. 1981b: Seismicity and neotectonic movement in the eastern United States and adjacent Canada. EOS, 62 (45), 967.

Barosh, P.J. 1983: Effects of the Miramichi earthquake in northeastern Maine and adjacent New Brunswick; in Preliminary report of the Miramichi, New Brunswick, Canada earthquake sequence of 1982, ed. A.E. Stevens, Canada Department of Energy, Mines and Resources, Earth Physics Branch, Open File Report 82-24, 94 pp.

Barosh, P.J. 1985: Northwest-trending basement fracture zones in the eastern United States and their role in controlling neotectonic movement and earthquakes. p. 195 in Proceedings of the Sixth International Conference on Basement Tectonics, ed. M.J. Aldrich, and A.W. Laughlin, Santa Fe, New Mexico, September 16-20, 1985.

Barosh, P.J. 1986: Seismotectonic study of the northeast United States. Earthquake Notes, 57 (4), 112.

Barosh, P.J. 1987: Neotectonic movement and earthquake assessment in the eastern United States. Abstracts with Programs, Geological Society of America, 19 (7), 580-581.

Basham, P.W. 1986: Single station (GRF broad-band array) teleseismic analysis of 1982 Miramichi, New Brunswick earthquake sequence. Earthquake Notes, 57 (4), 107-108.

Basham, P.W. and Adams, J. 1984: The Miramichi New Brunswick earthquakes: new surface thrust faulting in the northern Appalachians. Geoscience Canada, 11, 115-120.

Basham, P.W., Adams, J. and Wetmiller, R.J. 1984: Miramichi, New Brunswick earthquakes two years later - what have we learned? Earthquake Notes, 55 (1), 23.

Beaumont, C. and Boutilier, R. 1978: Tidal loading in Nova Scotia: results from improved ocean tide models. Canadian Journal of Earth Sciences, 15 (6), 981-993.

Beaumont, C. and Quinlan, G. 1977: Will changing the tides in the Bay of Fundy cause earthquakes? p. 254-276 in Fundy Tidal Power and the Environment, Proceedings of a Workshop on the Environmental Implications of Fundy Tidal Power, held in Wolfville, Nova Scotia, November 4-5, 1976, ed. G.R. Daborn, The Acadia University Institute, N.S., January 1977.

Bell, J.S. and Podrouzek, A.J. 1985: The present-day stress regime of the Scotian Shelf. Geophysics, 50 (8), 1369.

Boehner, R.C. 1981: Preliminary report on the geology and mineral deposits of the Loch Lomond Basin, Cape Breton Island. p. 153-165 in Nova Scotia Department of Mines and Energy, Mines and Minerals Branch, Report 81-1.

Boone, G.M. 1980: Bedrock geology of the Maine part of the Sherbrooke 2-degree quadrangle. in New England Seismotectonic Study Activities During the Fiscal Year 1979, ed. P.J. Barosh et al., Weston Observatory, Maryland, NRC FIN No. B5961.

Brinsmead, R.A. 1983: An examination of the dry well phenomenon, northeastern New Brunswick, in relation to the Miramichi earthquakes, winter 1982. New Brunswick Department of the Environment, Water Resources Branch, Groundwater Section, Departmental Report T-8303, 31 pp.

Brown, L.D. 1978: Recent vertical crustal movement along the east coast of the United States. Tectonophysics, 44, 205-231.

Buckley, D.E. 1981. Geological investigation of a selected area of the Sohm Abyssal Plain, western Atlantic: C.S.S. Hudson Cruise 80-016. Atomic Energy of Canada Limited, Technical Record TR-168.

Burgess, M.M. 1983: Summary of heat flow studies in the Sohm Abyssal Plain: C.S.S. Hudson Cruise 80-016. Atomic Energy of Canada Limited, Technical Record TR-242.

Burke, K.B.S. 1984: Earthquake activity in the Maritime Provinces. Geoscience Canada, 11 (1), 16-22.

Burke, K.B.S. and Comeau, R. (in press): Historical seismicity for the Passamaquoddy Bay region of New Brunswick for the period 1900 to 1961. Contract to Earth Physics Branch, Department of Energy, Mines and Resources, DSS contract 23233-7-3720/01-SZ.

Burke, K.B.S, Chandra J.J. and Fyffe, L. 1982: Geological and gravity investigations in the epicentral region of the 1982 Miramichi earthquakes, New Brunswick, Canada. Earthquake Notes, 53 (3), 15.

Burke, K.B.S., Bidiscombe, P. and Slauenwhite, S. 1986: An investigation of the historical record in New Brunswick, Canada. Earthquake Notes, 57 (4), 108.

Burke, K.B.S., Bidiscombe, P. Guimond, D. and Whelan, D. 1985: Historical seismicity of northern and eastern New Brunswick, 1807-1943. Contract to Department of Energy, Mines and Resources, DSS contract 22ST.23235-4-0734, 88 pp.

Burke, K.B.S., Carr, M.J., Poirier, R., Richard, D. and Vickers, A. 1986: Microearthquake survey of the Miramichi, New

Brunswick epicentral area from July 3rd to August 19th, 1985. Contract to Earth Physics Branch, Department of Energy, Mines and Resources, DSS contract 22ST.23235-4-734.

Burton, W.B. 1973: A correlation of the Triassic systems of Nova Scotia and the eastern United States with a possible origin of the North Mountain basalts. Unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Calder, J.H. 1984: Structural features of the Springhill coalfield with notes on geology and mining history. Nova Scotia Department of Mines, Open File Report 578.

Caldwell, D.W. and Weddle, T. 1983: Multiple-till localities in central Maine. p. 191-197 in The Greenville-Millinocket regions, north central Maine. ed. D.W. Caldwell et al., New England Intercollegiate Geological Conference, 75th Annual Meeting, 197 pp.

Carrera, G.H. 1984: Heights on a deforming earth. Department of Surveying Engineering, University of New Brunswick, Fredericton, New Brunswick, Technical Report 107, 150 pp.

Carter, D.C. 1986: A three-dimensional view of the Pugwash salt deposit, Cumberland County, Nova Scotia. in Nova Scotia Department of Mines and Energy, Mines and Minerals Branch, Report 87-1, 133-139.

Chiasson, T.C., Waugh, D.C.E. and Worth, J.K. 1973: Seismic refraction survey, Saint John Deep. New Brunswick Department of Natural Resources, Mineral Resources Branch, Topical Report 73-4, 26 pp.

Chiswell, P.G. 1986: Till geochemistry and mapping project. in Eleventh Annual Review of Activities - 1986, New Brunswick Department of Natural Resources and Energy, Mineral Resources Branch, Information Circular 86-2.

Chiswell, P.G. 1987: Surficial geology and geochemistry, Rollingdam area. in Twelfth Annual Review of Activities - 1987, New Brunswick Department of Natural Resources and Energy, Mineral Resources Branch, Information Circular 87-2.

Cole, E.J., Goudge, M.G. and Slater, R. 1963: Memorandum on subsidence problems in the Waverly gold district, Halifax County, Nova Scotia. Nova Scotia Department of Mines and Energy, Open File Report 568.

Cox, J.W. 1983: Long axis orientation in elongated boreholes and its correlation with rock stress data. Transactions 24th Annual Logging Symposium, Calgary, Alberta, Canada, June 27-30, 1983, Society Professional Well Log Analysts, 1, 17 pp.

Cranston, R.E. 1983: Summary of sediment and pore water analyses of samples from the Sohm Abyssal Plain: C.S.S. Hudson Cruise 80-016. Atomic Energy of Canada Limited, Technical Record TR-167.

Cranton, G.R. 1959: Memorandum on the Murphy cave-in, Inverness County, Nova Scotia. Nova Scotia Department of Mines and Energy, Open File Report 565.

Critchley, E.S. 1976: The recent evolution of Antigonish Harbour. Unpublished B.Sc. thesis, St. Francis Xavier University, Antigonish, Nova Scotia.

Crowdis, F. 1969: Structural and stratigraphic analysis of the south side of Antigonish Harbour. Unpublished B.Sc. thesis, St. Francis Xavier University, Antigonish, Nova Scotia.

Dale, T.N. 1907: The granites of Maine, with an introduction by G.O. Smith. United States Geological Survey, Bulletin 313, 202 pp.

Dalrymple, R.W. 1979: Wave-induced liquifaction: a modern example from the Bay of Fundy. Sedimentology, 26, 835-844.

Dalrymple, R.W., Amos, C.L. and McCann, S.B. 1982: Beach and nearshore depositional environments of the Bay of Fundy and southern Gulf of St. Lawrence. Excursion 6A, Eleventh Annual Congress on Sedimentology, International Association of Sedimentologists, McMaster University, Hamilton, Ontario, August 22-27, 1982, 116 pp.

Damuth, J.E., Tucholke, B.E., Coffin, M.F. 1979: Bottom processes on the Nova Scotian continental shelf revealed by 3.5 kHz echo character. EOS, 60 (46), 855.

Dickie, G.B. 1986: Cretaceous deposits of Nova Scotia. Nova Scotia Department of Mines and Energy, Paper 86-1, 54 pp.

Donohoe, H.V. and Wallace, P.I. 1979a: The new geological map of the Cobequid Highlands, Nova Scotia. p. 211-218 in Report of Activities, Mineral Resources Division, Nova Scotia Department of Mines, Report 80-1.

Donohoe, H.V. and Wallace, P.I. 1979b: Anatomy of the Cobequid Fault and its relation to the Glooscap and Cabot fault systems. in Report of Activities, Mineral Resources Division, Nova Scotia Department of Mines, Report 80-1, 162.

Donohoe, H.V. and Wallace, I. 1980: Structure and stratigraphy of the Cobequid Highlands, Nova Scotia. Trip 19, GAC-MAC field trip guidebook, Halifax '80, joint annual meeting of the Geological Association of Canada and the Mineralogical Association of Canada, 63 pp.

Doyle, E.M. 1979: Geology of the Bear River area, Digby and Annapolis counties, Nova Scotia. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Dunlop, W.B. 1952: Pleistocene and Recent deposits of the Church Point area, Nova Scotia. Unpublished M.A. thesis, Acadia University, Wolfville, Nova Scotia.

Durling, P.W. and Fader, G.B. 1986: Geological assessment of shallow faults and structural dsturbances from the eastern Scotian Shelf and Laurentian Channel area. Geological Survey of Canada, Open File Report 1371.

Ebel, J.E. (in press): The seismicity of Maine. Maine Geological Survey.

Ebel, J.E. and Vudler, V. 1982: Foreshocks and aftershocks of the New Brunswick earthquake of January 9, 1982. Earthquake Notes, 53 (1), 16.

Embley, R.M. and Jacobi, R. 1986: Mass wasting in the western North Atlantic. p. 479-490 in The Geology of North America, Volume M: The Western North Atlantic Region, ed. P.R. Vogt, and B.E. Tucholke, Geological Society of America.

Emery, K.O., Uchupi, E., Phillips, J.D., Bowin, C.D., Bunce, E.T. and Knott, S.T. 1970: Continental rise off eastern North America. American Association of Petroleum Geologists Bulletin, 54, 44-108.

Ervine, W.B. and Bell, J.S. 1987: Subsurface in situ stress magnitudes from oil-well drilling records: an example from the Venture area, offshore eastern Canada. Canadian Journal of Earth Sciences, 24, 1748-1759.

Fader, G.B., King, L.H. and Josenhans, H.W. 1982: Surficial geology of the Laurentian Channel and the western Grand Banks of Newfoundland. Geological Survey of Canada, Paper 81-22, 37 pp.

Feld, J. 1966: Rock movements from load release in excavated cuts. p. 139-140 in Proceedings of the First International Congress of the Society for Rock Mechanics, Lisbon.

Finamore, P.F. 1977. Granular resources in parts of the St. George (21 G/2) and McDougall Lake (21 G/2) map-areas. New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 79-13, 78 pp.

Finamore, P.F. 1979a. Granular aggregate resources of Campbellton, map-area 21 O/15. New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 79-12, 79 pp.

Finamore, P.F. 1979b. Granular aggregate resources of Tetagouche Lakes, map-areas 21 O/9. New Brunswick Department of Natural Resources, Mineral Resources Branch, Topical Report 77-1, 145 pp.

Finamore, P.F. 1981. Granular aggregate resources in parts of the Woodstock and Millville map areas, New Brunswick (NTS 21 J/4 and 21 J/3). New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 81-4, 145 pp.

Finamore, P.F. and Lohse, H. 1977: Granular resources in the Loch Lomond map-area. New Brunswick Department of Natural Resources, Mineral Resources Branch, Topical Report 77-9, 101 pp.

Finley, W.E. 1978: Sedimentary structures revealed by seismic reflection profiles across the continental rise, slope and outer shelf southwest of Nova Scotia. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Foley, J.E., Ebel, J.E. and Kafka, A.L. 1984: Recent and historic seismicity of southeastern Maine. Abstract in Joint Programme with Abstracts, 18th Annual Congress, Canadian Meteorological and Oceanographic Society, Dalhousie University, Halifax, Nova Scotia, 29 May-1 June 1984.

Fyffe, L.R. 1983: Joint patterns within the epicentral area of the 1982 Miramichi earthquake. New Brunswick Department of Natural Resources and Energy, Open File Report 83-13, 19 pp.

Gadd, N.R. 1971: Quaternary geology of southwest New Brunswick with particular reference to Fredericton area. Geological Survey of Canada, Paper 71-34, 31 pp.

Ganong, W.F. 1896. Notes on the natural history and physiography of New Brunswick. Bulletin of the Natural History Society of New Brunswick, Number XIV, 40-42.

Ganong, W.F. 1903: Notes on the natural history and physiography of New Brunswick. Bulletin of the Natural History Society of New Brunswick, V (XXI), part I, 37-38.

Ganong, W.F. 1904: Notes on the natural history and physiography of New Brunswick. Bulletin of the Natural History Society of New Brunswick, V (XXII), part II, 237.

Gates, O. 1978: Faulting and seismicity in the Machias-Eastport area, Maine. Abstracts with Programs, Geological Society of America, 10 (2), 43.

Genes, A.N. and Newman, W.A. 1980: Wisconsinan glaciation of northern Aroostook County, Maine. p. 179-187 in A guidebook to the geology of northeastern Maine and neighbouring New Brunswick, ed. D.C. Roy et al., New England Intercollegiate Geological Conference, 72nd Annual Meeting.

Gerber, R.G. 1979. Late Pleistocene deformations of bedrock and till, Sears Island, Maine. Abstracts with Programs, Geological Society of America, 10 (2), 44-45.

Goldthwait, J.W. 1924: Physiography of Nova Scotia. Geological Survey of Canada, Memoir 140, 179 pp.

Goodman, N.R. 1952: Gypsum and anhydrite in Nova Scotia. Nova Scotia Department of Mines and Energy, Memoir 1.

Grant, D.R. 1970a: Recent coastal submergence of the Maritime Provinces, Canada. Unpublished Ph.D. thesis, Cornell University, Ithaca, New York.

Grant, D.R. 1970b: Recent coastal submergence of the Maritime provinces. Canadian Journal of Earth Sciences, 7, 676-689.

Grant, D.R. 1975a: Surficial geology of northern Cape Breton Island, Geological Survey of Canada, Paper 75-1, Part A.

Grant, D.R. 1975b: Recent coastal submergence of the Maritime Provinces. Proceedings of the Nova Scotia Institute of Science, 27, supplement 3, 83-102.

Grant, D.R. 1977: Workshop on sea-level rise and subsidence in the Maritimes. Geoscience Canada, 4, 144-146.

Grant, D.R. 1980a: Quaternary sea-level changes in Atlantic Canada as an indication of crustal delevelling; p. 201-214 in Earth Rheology, Isostasy and Eustasy, ed. N.-A. Mörner, John Wiley and Sons Ltd., New York, 599 pp.

Grant, D.R. 1980b: Quaternary stratigraphy of southwestern Nova Scotia: glacial events and sea-level changes. Trip 9, GAC-MAC field trip guidebook, Halifax '80, joint annual meeting of the Geological Association of Canada and the Mineralogical Association of Canada, 63 pp.

Grant, D.R. 1985: The emerged interglacial littoral platform in Atlantic Canada - a stratigraphic, geodynamic and geoidal datum plane. Abstract in GAC-MAC, Program with Abstracts, Volume 10, Geological Association of Canada-Mineralogical Association of Canada.

Grant, D.R. 1987: Glacial advances and sea-level changes, southwestern Nova Scotia, Canada. p. 427-431 in Geological Society of America Centennial Field Guide - Northeastern Section, Volume 5, ed. D.C. Roy.

Grant, D.R. (in press): Quaternary movement of the Aspy Fault. Canadian Journal of Earth Sciences.

Greiner, H.R. 1965: Charlo Map-Area. New Brunswick Department of Natural Resources, Mineral Resources Branch, Geological Note Series, PM 65-2, 27 pp.

Greiner, H.R. 1970: Geology of the Charlo area 21 O/16, Restigouche County, New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Series 70-2, 18 pp.

Hamilton, J.B. 1962: Geological notes, Codys, Queens and Kings Counties. New Brunswick Department of Lands and Mines, Mines Branch, Geological Note Series, P.M. 59-5, 18 pp.

Hamilton, J.B. 1968: Carbonate deposits in the Nauwigewauk, Elliott Road and Torryburn areas, Kings County. New Brunswick Department of Natural Resources, Mineral Resources Branch, Report of Investigation 8, 18 pp.

Harrison, W. and Lyon, C.J. 1963: Sea-level and crustal movements along the New England-Acadian shore, 4,500-3,000 B.P. Journal of Geology, **71**, 96-103.

Heezen, B.C. and Drake, C.L. 1964: Grand Banks slump. Geological Society of America Bulletin, **48**, 221-225.

Heezen, B.C. and Ewing, M. 1952: Turbidity currents and submarine slumps, and the 1929 Grand Banks earthquake. American Journal of Science, 250, 849-873.

Heezen, B.C. and Hollister, C.D. 1971: The face of the deep. Oxford University Press, New York, N.Y. 650 pp.

Hickox, C.F. 1958: Geology of the central Annapolis Valley, Nova Scotia. Unpublished Ph.D. thesis, Yale University, New Haven, Connecticut, 279 pp.

Hill, P.R. 1982: Slip-sliding away - morphology and process on the Nova Scotian continental slope. Maritime Sediments and Atlantic Geology, 18, 50-51.

Hill, P.R. 1983: Detailed morphology of a small area on the Nova Scotia continental slope. Marine Geology, 53, 55-76.

Hill, P.R. 1984. Sedimentary facies of the Nova Scotian upper and middle continental slope, offshore eastern Canada. Sedimentology, 31, 293-309.

Hill, P.R., Piper, D.J.W. and Normark, W.R. 1983: Pisces IV submersible dives on the Scotian slope at 63° W. Geological Survey of Canada, Paper 83-1A, 65-69.

Hilton, E.R. 1953: Geology of the Williams Point area, Antigonish County, Nova Scotia. Unpublished M.Sc. thesis, Massachusetts Institute of Technology, Boston, Massachusetts.

Honig, C.A. and Scott, D.B. 1987: Postglacial stratigraphy and sea-level change in southwestern New Brunswick. Canadian Journal of Earth Sciences, 24, 354-364.

Hughes, O.L. 1956: Surficial geology of Shubenacadie map-area. Geological Survey of Canada, Paper 56-3.

Hunter, M. and Lavergne, C. 1982: Granular aggregate resources of Fosterville (21 G/13) and Canterbury (21 G/14). New Brunswick Department of Natural Resources, Mineral Resources Division, Open File Report 82-4, 123 pp.

Hunter and Associates. 1982: Fundy coastal zone study, Volume IV: Map Atlas. New Brunswick Department of Natural Resources and Energy, Mineral Resources Division, Miscellaneous Report 3, 209 pp.

Hussey II, A.M. 1985: The bedrock geology of the Bath and Portland 2 degree map sheets, Maine. Maine Geological Survey, Open File Report, 85-87, 82 pp.

Hutt, G.M. 1984: Report on subsidence of the rail track along the Avon River section of the Dominion Atlantic Railway. Nova Scotia Department of Mines and Energy, Open File Report 590.

Hwang, S.-G. 1985: Geology and structure of the Yarmouth area, southwestern Nova Scotia. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia, 237 pp.

Jacques/McLelland Geosciences Inc. 1982: Seabed stability of the continental shelf of eastern Canada. Report to Department of Supply and Services for Atlantic Geoscience Centre, project G001, 31 March 1982, 130 pp.

Janes, J.R. 1978: The great Canadian outback. Douglas & McIntyre Ltd., Vancouver, British Columbia, 144 pp.

Jansa, L.F. and Wade, J.A. 1975: Geology of the continental margin off Nova Scotia and Newfoundland. Geological Survey of Canada, Paper 74-30, 2, 51-105.

Jones, R.A. 1961. Wild Goose-Baker Lake area, Restigouche and Madawaska counties. Department of Lands and Mines, Mines Branch, Geological Note Series, P.M. 58-1, 14 p.

Josenhans, H.W., King, L.H. and Fader, G.B. 1978: A side-scan sonar mosaic of pockmarks on the Scotian Shelf. Canadian Journal of Earth Sciences, 15, 831-840.

Kain, S.W. 1898: List of recorded earthquakes in New Brunswick. Bulletin of the Natural History Society of New Brunswick, IV (XVI) part I, 16-22.

Kain, S.W. 1904: Recent earthquakes in New Brunswick. Bulletin of the Natural History Society of New Brunswick, V (XXII) part II, 243-245.

Keen, C.E. 1978: Thermal history and subsidence of rifted continental margins - evidence from wells on the Nova Scotian and Labrador shelves. Canadian Journal of Earth Sciences, 16, 505-522.

Keen, C.E., Keen M.J., Barrett, D.L. and Heffler, D.E. 1975: Some aspects of the ocean-continent transition at the continental margin of eastern North American. Geological Survey of Canada, Paper 74-30, 2, 189-197.

Keen, M.J. 1973: Subsidence and fracturing on the continental margin of eastern Canada. p. 23-42 in Earth Science Symposium on Offshore Eastern Canada, ed. P.J. Hood, Geological Survey of Canada, Paper 71-23.

Kindle, E.M. 1917: Deformation of unconsolidated beds in Nova Scotia and southern Ontario. Geological Society of America Bulletin, 28, 323-334.

King, L.H. 1975: Geosynclinal development on the continental margin south of Nova Scotia and Newfoundland. Geological Survey of Canada, Paper 74-30, 2, 199-206.

King, L.H. and MacLean, B. 1970: Continuous seismic-reflection study of Orpheus gravity anomaly. American Association of Petroleum Geologists Bulletin, 54 (11), 2007-2031.

King, L.H. and MacLean, B. 1976: Geology of the Scotian Shelf. Geological Survey of Canada, Paper 74-31.

Koons, D. (in press): Postglacial bedrock faulting in Maine. Maine Geological Survey Bulletin.

Kranck, K. 1972: Geomorphic development and post-Pleistocene sea level changes, Northumberland Strait, Maritime Provinces. Canadian Journal of Earth Sciences, 9, 835-844.

Lajtai, E.Z. and Stringer, P. 1981: Joints, tensile strength and preferred fracture orientation in sandstones, New Brunswick and Prince Edward Island, Canada. Maritime Sediments and Atlantic Geology, 17 (2), 70-87.

Lambert, A. 1969: A tiltmeter study of the response of the earth to ocean tide loading. Unpublished Ph.D. thesis, Dalhousie University, Halifax, Nova Scotia.

Lambert, A. and Beaumont, C. 1977: Nanovariations in gravity due to seasonal groundwater movements: implications for the gravitational detection of tectonic movements. Journal of Geophysical Research, 82 (2), 297-306.

Lambert, A. and Vanicek, P. 1979: Contemporary crustal movements in Canada. Canadian Journal of Earth Sciences, 16, 647-668.

Lamothe, M. 1986: A progress report on the Miramichi surficial geology and till geochemistry project, Miramichi zone, New Brunswick. in Eleventh Annual Review of Activities - 1986, New Brunswick Department of Natural Resources and Energy, Mineral Resources Branch, Information Circular 86-2.

Leblanc, G. and Burke, K.B.S. 1985: A re-evaluation of the 1817, 1855, 1869 and 1904, Maine-New Brunswick area earthquakes. Earthquake Notes, 56 (4), 107-123.

Lee, F.T., Miller, D.R. et al. 1979: The relation of stresses in granite and gneiss near Mount Waldo, Maine, to structure, topography, and rockbursts. p. 663-669 in 20th Symposium on Rock Mechanics, Austin, Texas.

Legget, R.F. 1980: Glacial geology of Grand Manan Island, New Brunswick. Canadian Journal of Earth Sciences, 17, 440-452.

Liew, M.Y.-C. 1976: Structure, geochemistry and stratigraphy of Triassic rocks, north shore of Minas Basin, Nova Scotia. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Lodin, M. 1984: Structural analysis of the Miramichi earthquake epicentral area using remote sensing techniques. Unpublished technical report, Nova Scotia Land Survey Institute, Lawrencetown, Nova Scotia, 119 pp.

Lohse, H. 1977: Granular resources of Musquash map area, 21 G/1. New Brunswick Department of Natural Resources, Mineral Resources Branch, Topical Report 77-2, 70 pp.

Lollis, E.W. 1959: Geology of Digby Neck and Long and Brier Islands, Digby County, Nova Scotia. Unpublished M.Sc. thesis, Yale University, New Haven, Connecticut.

MacKenzie, G.S. 1940: The St. Stephen map-area, Charlotte County, N.B. New Brunswick Department of Lands and Mines, Mining Section, Paper 40-6, 46 pp.

MacLean, B. and King, L.H. 1971: Surficial geology of the Banquereau and Misaine Bank map area. Geological Survey of Canada, Paper 71-52, 19 pp.

MacNeil, H.R. 1951: Pleistocene geology of the Wolfville area. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia, 59 pp.

Mann, R.C. 1977: Subsidence of the Scotian Basin: a theoretical model. Unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Manzer, D.P. 1947: Gypsum deposits at Upham, Kings County, New Brunswick. New Brunswick Department of Lands and Mines, Mines Branch, Paper 47-6, 18 pp.

Marlowe, J.I. The geology of part of the continental slope near Sable Island, Nova Scotia. Geological Survey of Canada, Paper 65-38.

Matthew, G.F. 1894a: Post-glacial faults at St. John, N.B. American Journal of Science, 148, 501-503.

Matthew, G.F. 1894b: Movements of the earth's crust at St. John, N.B. in post-glacial times. Bulletin of the Natural History Society of New Brunswick, 3 (12), 34-42.

Mawer, C.K. and Williams, P.F. 1985: Crystalline rocks as possible paleoseismicity indicators. Geology, 13, 100-102.

McAlpine, D.F. 1983: Status and conservation of solution caves in New Brunswick. The New Brunswick Museum, Publications in Natural Science, No. 1, 28 pp.

McCutcheon, S. and Thibault, J. 1981: Environmental geology of Sussex and Sussex Corner. New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 81-29, 18 pp.

McKay, D.A., Williams, J.B., Bowlby, J.R. and Grass, J.D. 1985: Miramichi epicentral area - in situ stress pilot project. Ontario Hydro Research Division, Report No. 85-185-K, 261 pp.

McLeod, M. 1973: The geology of Campobello Island, southwestern New Brunswick. Unpublished M.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick.

Melvin, R.L. 1966: The surficial geology of Ben Lomond area, Saint John and Kings Counties, New Brunswick. M.Sc. thesis, Department of Geology, University of New Brunswick, Fredericton, N.B.

Merriam, C.H. 1886: On pre-historic remains, and on an interment of the early French Period, at Tabusintac River, N.B. Bulletin of the Natural History Society of New Brunswick, No. 5, 14-19.

Mörner, N.-A. 1972: The first report on till wedges in Europe and Late Weichselian ice flows over southern Sweden. Geologiska Föreningens i Stockholm Förhandlingar, 94, 581-587.

Mörner, N.-A. 1973: A new find of till wedges in Nova Scotia, Canada. Geologiska Föreningens i Stockholm Förhandlingar, 95, 272-273.

Mörner, N.-A., ed. 1987: INQUA 1987: Bulletin of the INQUA Neotectonics Commission, Number 10, June 1987, inside of front cover.

Neale, E.R.W. 1955: Pleasant Bay. Geological Survey of Canada, Paper 55-24.

Neale, E.R.W. 1963a: Geology, Pleasant Bay, Nova Scotia. Geological Survey of Canada, Map 1119A.

Neale, E.R.W. 1963b: Geology, Dingwall, Cape Breton Island. Geological Survey of Canada, Map 1124A.

Neale, E.R.W. 1964: Geology, Cape North, Nova Scotia. Geological Survey of Canada, Map 1150A.

Newberg, D.W. 1983: Analysis of structural features in southern Piscataquis County, Maine. Maine Geological Survey, Open File Report 83-6, 17 pp.

Newman, W.A. 1979: Possibility of Pleistocene-Holocene movement along the Oak Bay Fault on the Maine-New Brunswick border. Maine Geological Survey, Open File Report 79-20, 7 pp.

Nguyen, B.V. and Herrmann, R.B. 1984. Surface-wave focal mechanisms for some earthquakes in eastern North America. EOS, 65 (16), 240.

Norman, G.W.H. 1935: Lake Ainslie map-area. Geological Survey of Canada, Memoir 177.

Northeast Utilities Service Company. 1984: Summary Geological, Geophysical and Seismological Studies, New Brunswick & Millstone. Topical Report, 13 pp.

Notley, K.R. 1980: Analysis of the Springhill mine disaster (October 23, 1958). Unpublished Ph.D. thesis, Queen's University, Kingston, Ontario.

Novak, I.D. 1988: Slope failures in the Presumpscot Formation, Cumberland County, Maine. Abstracts with Programs, Geological Society of America, 20 (1).

Novak, I.D. and LePage, C. 1986: Landslide inventory of Maine: a preliminary report. Abstracts with Programs, Geological Society of America, 18, 58.

Novak, I.D., Swanson, M. and Pollock, S. 1984: Morphology and structure of the Gorham, Me., landslide. Abstracts with Programs, Geological Society of America, 16, 53-54.

O'Leary, D.W. 1986: The Munson-Nygren slide: a major lower-slope slide off Georges Bank. Marine Geology, 72, 101-114.

O'Neill, D.A. 1985: A study of anisotropic granodiorite from the 1982 Miramichi earthquake epicentre. B.Sc. thesis, University of New Brunswick, Fredericton, New Brunswick, 151 pp.

Ogden, K.F. 1980: An ice marginal lake in Annapolis Basin at the close of the Late Wisconsinan. Unpublished B.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Pagiatakis, S. and Vaníček, P. 1985: Atmospheric perturbations of tidal tilt and gravity measurements at the U.N.B. earth tides station. Proceedings of the Tenth International Symposium on Earth Tides, 905-922.

Paterson, N.R. and Jagodits, F.L. 1966: Report on geological-geophysical study, Minas Basin, Bay of Fundy, Nova Scotia. Report for the Atlantic Development Board by Huntec Limited, March 1966, 128 pp.

Pictou County Undermining & Subsidence Study. 1981: Mine subsidence in Pictou County. Report on mine subsidence in Pictou County, Nova Scotia. Available from Nova Scotia Department of Mines and Energy.

Piper, D.J.W. and Normark, W.R. 1982a: Effects of the 1929 Grand Banks earthquake on the continental slope off eastern Canada. Geological Survey of Canada, Paper 82-1B, 147-151.

Piper, D.J.W. and Normark, W.R. 1982b: Acoustic interpretation of Quaternary sedimentation and erosion on the channelled upper Laurentian Fan, Atlantic margin of Canada. Canadian Journal of Earth Sciences, 19, 1974-1984.

Piper, D.J.W. and Sparkes, R. 1987: Proglacial sediment instability features on the Scotian Slope at 63° W. Marine Geology, 76, 15-31.

Piper, D.J.W. and Wilson, E. 1983: Surficial geology of the upper Scotian Slope west of Verrill Canyon. Geological Survey of Canada, Open File Report 939.

Piper, D.J.W., Farre, J.A. and Shor, A. 1985a: Late Quaternary slumps and debris flows on the Scotian Slope. Geological Society of America Bulletin, 96, 1508-1517.

Piper, D.J.W., Stow, D.A.V. and Normark, W.R. 1985b: Laurentian Fan, Atlantic Ocean. p. 137-142 in Submarine fans and related turbidite systems, (Frontiers in sedimentary geology), ed. A.H. Bouma, et al., Springer-Verlag, New York, 351 pp.

Piper, D.J.W., Sparkes, R., Farre, J.A. and Shor, A. 1983: Mid-range sidescan and 4.5 kHz sub-bottom profiler survey of mass-movement features, Scotian Slope at 61°40'W. Geological Survey of Canada, Open File Report 938.

Plumb, R.A. and Cox, J.W. 1987: Stress directions in eastern North America determined to 4.5 km from borehole elongation measurements. Journal of Geophysical Research, 92 (B6), 4805-4816.

Poirier, R. 1985: Tsunamis in the Atlantic provinces. Unpublished senior undergraduate thesis, No. T-1246, Department of Civil Engineering, University of New Brunswick, Fredericton, New Brunswick, 27 pp.

Prime, G.A. 1980: Post-Pleistocene sea level changes in the Baie Verte estuary (Northumberland Strait) as revealed by foraminiferal studies. Unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Prowell, D.C. 1983: Index of faults of Cretaceous and Cenozoic age in the eastern United States. USGS Department of the Interior, Miscellaneous Field Studies, Map MF-1269, sheet 2, 1:2,500,000.

Quinlan, G. 1984: Postglacial rebound and the focal mechanism of eastern Canadian earthquakes. Canadian Journal of Earth Sciences, 21, 1018-1023.

Quinlan, G. and Beaumont, C. 1981: A comparison of observed and theoretical relative sea level in Atlantic Canada. Canadian Journal of Earth Sciences, 18, 1146-1163.

Rampton, V.N. and Paradis, S. 1981a: Quaternary geology of Woodstock map-area (21 J), New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Report 81-1, 37 pp.

Rampton, V.N. and Paradis, S. 1981b: Quaternary geology of Amherst map-area (21 H), New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Map Report 81-3, 36 pp.

Rampton, V.N., Gauthier, R.C. Thibault, J. and Seaman, A.A. 1984: Quaternary geology of New Brunswick. Geological Survey of Canada, Memoir 416, 77 pp.

Rappol, M. and Shilts, W.W. (in press): Evidence for late or postglacial seismic events: Temiscouata-Madawaska Valley, Quebec-New Brunswick. Abstract submitted to 1988 GAC-MAC meeting in St. John's, Newfoundland, May 1988.

Rast, N., Burke, K.B.S. and Rast, D.E. 1979: The earthquakes of Atlantic Canada and their relationship to structure. Geoscience Canada, 6 (4), 173-180.

Reilinger, R. 1987: Reanalysis of crustal warping in coastal Maine. Geology, 15, 958-961.

Retelle, M.J. and Konecki, K. 1986: Late Quaternary stratigraphy of the lower Androscoggan Valley, southern Maine. p. 20-36 in Guidebook For Field Trips in Southwestern Maine, ed. D.W. Newberg, New England Intercollegiate Geological Conference, 78th Annual Meeting.

Rice, G.S. 1924: Occurrence of bumps in the Springhill No. 2 Mine of the Dominion Coal Company, Limited. Nova Scotia Department of Public Works and Mines, Mines Report.

Rogers, C.L. 1980: Faulting along the Penobscot Lineament on Verona Island, Maine. in New England Seismotectonic Study Activities During the Fiscal Year 1979, ed. P.J. Barosh et al., Weston Observatory, Maryland, NRC FIN No. B5961.

Rouleau, P. 1984: Tidal tilt observations around the Bay of Fundy and Gulf of Maine: implications for crustal structure and ocean tides. Abstract in Joint Programme with Abstracts, 18th Annual Congress, Canadian Meteorological and Oceanographic Society, Dalhousie University, Halifax, Nova Scotia, 29 May-1 June 1984.

Ruffman, A. 1987: Newly-recognized tsunami in Atlantic Canada. Maritime Sediments and Atlantic Geology, 23 (2), 106.

Ruffman, A. and Peterson, J. (in press (a)): Pre-confederation historical seismicity of Nova Scotia with an examination of selected later events. Geomarine Associates Ltd, Halifax, Nova Scotia, Project 85-69, Contract Report, DSS Contract No. OSG85-001411 for Canada Department of Energy, Mines and Resources, Earth Physics Branch, Division of Seismology and Geomagnetism, Open File.

Ruffman, A. and Peterson, J. (in press (b)): Felt effects of the Monday, November 18, 1929 "Grand Banks" earthquake and its aftershocks, originating in the Laurentian Slope seismic zone, as experienced in Nova Scotia, Prince Edward Island and Bermuda. Geomarine Associates Ltd, Halifax, Nova Scotia, Project 86-21, Contract Report, DSS Contract No. 23233-6-3548/01-SS for Canada Department of Energy, Mines and Resources, Earth

Physics Branch, Division of Seismology and Geomagnetism, Open File.

Ruitenberg, A.A. 1970: Mineralized structures in the Johnson Croft, Annidale, Jordan Mountain and Black River areas. New Brunswick Department of Natural Resources, Mineral Resources Branch, Report of Investigation 13, 28 pp.

Ruitenberg, A.A. and McCutcheon, S.R. 1978: Engineering geology of the Lorneville Cove landslide. New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 78-7, 7 pp.

Ruitenberg, A.A. and Thibault, J. 1981: Bedrock, surficial and environmental geology of the village of Westfield, N.B. New Brunswick Department of Natural Resources, Mineral Resources Division, Open File 81-32, 11 pp.

Ruitenberg, A.A., Buttimer, S.M. and McCutcheon, S.R. 1975: Bedrock and surficial geology, East Musquash watershed. New Brunswick Department of Natural Resources, Mineral Resources Branch, Topical Report 75-4, 22 pp.

Ruitenberg, A.A., McCutcheon, S.R. and Venugopal, D.V. 1976: Recent gravity sliding and coastal erosion, Devil's Half Acre, Fundy Park, New Brunswick; geological explanation of an old legend. Geoscience Canada, 3 (3), 237-238.

Ruitenberg, A.A. (in press): Deformation in Quaternary deposits of southwestern New Brunswick - possible neotectonic implications. Abstract submitted to 1988 GAC-MAC meeting in St. John's, Newfoundland, May 1988.

Saikia, C.K. and Herrmann, R.B. 1985: Application of waveform modelling to determine focal mechanisms of four 1982 Miramichi aftershocks. Bulletin of the Seismological Society of America, 75 (6), 1021-1040.

Sandford, T.C. 1988: Landslide potential in sensitive glaciomarine sediments near Westbrook, Maine. Abstracts with Programs, Geological Society of America, 20 (1), 67.

Schroeder, J. and Arseneault, S. 1978: Discussion d'un karst dans le gypse d'Hillsborough, Nouveau-Brunswick. Géographie Physique et Quaternaire, XXXII (3), 249-262.

Scott, D.B. and Greenberg, D.A. 1983: Relative sea-level rise and tidal development in the Fundy tidal system. Canadian Journal of Earth Sciences, 20, 1554-1564.

Scott, D.B., Medioli, F.S. and Duffett, T.E. 1984: Holocene rise of relative sea level at Sable Island, Nova Scotia, Canada. Geology, 12, 173-176.

Scott, D.B., Medioli, F.S. and Miller, A.L. 1987: Holocene sea levels, paleoceanography, and late glacial ice configuration near the Northumberland Strait, Maritime Provinces. Canadian Journal of Earth Sciences, 24, 668-675.

Scott, J.S. 1963: Engineering geological reconnaissance of Passamaquoddy Bay tidal power project, N.B. Geological Survey of Canada, Topical Report 64.

Seaman, A.A. 1981: Granular agregate resources, Burtts Corner (NTS 21 J/2), New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 81-28, 131 pp.

Seaman, A.A. 1982a: The Late Quaternary history of the Burtts Corner area, New Brunswick. Unpublished M.Sc. thesis, Department of Geography, University of Toronto, Toronto, Ontario.

Seaman, A.A. 1982b: Granular aggregate resources, McAdam (NTS 21 G/11) and Forest City (NTS 21 G/12), New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 82-14, 101 pp.

Seaman, A.A. 1987: Granular aggregate resources, Cape Spencer (NTS 21 H/4) map area, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources Branch, Open File Report 87-4.

Seaman, A.A. and Thibault, J. 1981: Granular aggregate resources, Fredericton (NTS 21 G/15). New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 81-27, 89 pp.

Seaman, A.A. and Thibault, J. 1986: Granular aggregate resources of the Central Lowland area, east-central New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources Branch, Open File Report 86-1, 219 pp.

Seeber, L., Thorson, R.M. and Clayton, W. 1985: Liquifaction and clastic injection in postglacial sediments of eastern Connecticut: evidence for large prehistoric earthquakes? Earthquake Notes, 56 (3), 70.

Smith, D.A., Scott, D.B. and Medioli, F.S. 1984: Marsh foraminifera in the Bay of Fundy: modern distribution and application to sea-level determinations. Maritime Sediments and Atlantic Geology, 20, 127-142.

Smith, D.C. and Bridges, A.E. 1983: Historical dating of salt marsh dikes in coastal Maine/historically recorded earthquakes in eastern Maine. Maine Geological Survey, Open File Report 83-10, 12 pp.

Smith, G.W. 1984: Surficial geology, portions of the Grand Falls Lake area: an investigation of evidence for Holocene faulting. Maine Geological Survey, Open File Report 84-9, 3 pp.

Smith, L. 1973: Late Mesozoic and Cenozoic of the Sable Island Bank and Grand Banks. p. 267-283 in Earth Science Symposium on Offshore Eastern Canada, ed. P.J. Hood, Geological Survey of Canada, Paper 71-23.

Smith, W.E.T. 1962: Earthquakes of eastern Canada and adjacent areas 1534-1927. Dominion Observatory, SDepartment of Mines and Technical Surveys, 26 (5), 271-301.

Stanley, D.J. and Silverberg, N. 1969: Recent slumping on the continental slope off Sable Island Bank, southeast Canada. Earth and Planetary Science Letters, 6, 123-133.

Stea, R.R. 1987: Quaternary glaciations, geomorphology, and sea-level changes: Bay of Fundy region, July 20-26, 1987. International advanced course on Late Quaternary sea-level correlation and applications, NATO Advanced Study Institutes Programme, International Geological Correlation Program, Project 200, 79 pp.

Stea, R.R., Finck, P.W. and Wightman, D.M. 1985: Quaternary geology and till geochemistry of the western part of Cumberland County, Nova Scotia (Sheet 9). Geological Survey of Canada, Paper 85-17.

Stead, G. 1906. Notes on a grindstone quarry at Stonehaven, Gloucester Co., N.B. Bulletin of the Natural History Society of New Brunswick, V (24), 407-408.

Stevens, A.E., ed. 1983: Preliminary report of the Miramichi, New Brunswick, Canada earthquake sequence of 1982. Canada Department of Energy, Mines and Resources, Earth Physics Branch, Open File Report 82-24, 94 pp.

Stevens, G.R. 1977: Geology and tectonic framework of the Bay of Fundy-Gulf of Maine region. in Fundy Tidal Power and the Environment, Proceedings of a Workshop on the

Environmental Implications of Fundy Tidal Power, held at Wolfville, Nova Scotia, November 4-5, 1976, ed. G.R. Daborn, The Acadia University Institute, N.S., January 1977.

Stevens, G.R. 1987: Jurassic basalts of northern Bay of Fundy region, Nova Scotia. p. 415-420 in Geological Society of America Centennial Field Guide - Northeastern Section, Volume 5. ed. D.C. Roy.

Stow, D.A.V. 1975: The Laurentian Fan: Late Quaternary stratigraphy. Unpublished M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Street, R. and Lacroix, A.V. 1979: An empirical study of New England seismicity: 1727-1927. Bulletin of the Seismological Society of America, 69 (1), 159-175.

Stringer, P. and Wardle, R.J. 1973: Post-Carboniferous and post-Triassic structures in southern New Brunswick. p. 88-95 in Field Guide to Excursions, New England Intercollegiate Geological Conference, ed. N. Rast, 65th Annual Meeting.

Swayne, L.E. 1952: Pleistocene geology of the Digby area, Nova Scotia. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Swift, S.A. 1987: Late Cretaceous-Cenozoic development of outer continental margin, southwestern Nova Scotia. The American Association of Petroleum Geologists Bulletin, 71 (6), 678-701.

Tarralle, B. 1972: Geotechnical properties of the Red Head, N.B., clay. Unpublished M.Sc. thesis, Department of Civil Engineering, University of New Brunswick, Fredericton, New Brunswick.

Thibault, J. 1979: Granular aggregate resources of the Grandmaison (NTS 21 N/9) and the Edmundston (NTS 21 N/8) map areas. New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 79-31, 115 pp.

Thibault, J. 1980: Granular aggregate resources, Saint-André (NTS 21 O/4), Aroostook (NTS 21 J/13), New Brunswick. New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 80-6, 128 pp.

Thibault, J. 1981: Granular aggregate resources of Fredericton Junction (NTS 21 G/10). New Brunswick Department of

Natural Resources, Mineral Resources Branch, Open File Report 81-15, 66 pp.

Thibault, J. 1982: Granular aggregate resources of Rollingdam (NTS 21 G/6) and St. Stephen (NTS 21 G/3). New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 82-15, 91 pp.

Thibault, J. 1983: Granular aggregate resources of McDougall Lake (NTS 21 G/7). New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 83-6, 62 pp.

Thibault, J. 1985: Granular aggregate resources and surficial geology of Sisson Branch Reservoir (21 0/6). New Brunswick Department of Mines and Energy, Open File Report 85-3, 51 pp.

Thibault, J. 1987a: Granular aggregate resources of the Acadian Peninsula, northeastern New Brunswick. New Brunswick Department of Mines and Energy, Minerals and Energy Division, Open File Report 87-2.

Thibault, J. 1987b: Aggregate resources of the Madawaska Panhandle, northwestern New Brunswick. New Brunswick Department of Mines and Energy, Minerals and Energy Division, Open File Report 87-3.

Thompson, J.P. 1974: Stratigraphy and geochemistry of the Scots Bay Formation. Unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Thompson, W.B. 1981: Postglacial faulting in the vicinity of the Norumbega Fault Zone, eastern Maine. Maine Geological Survey, Open File Report 81-48, 22 pp.

Thompson, W.B. 1986: Glacial geology of the White Mountain foothills, southwestern Maine. p. 275-288 in Guidebook for Field Trips in Southwestern Maine, ed. D.W. Newberg, New England Intercollegiate Geological Conference, 78th Annual Meeting.

Thorpe, R.I. 1958: Pleistocene geology of the Berwick area, Nova Scotia. Unpublished B.Sc. thesis, Acadia University, Wolfville, Nova Scotia. 76 pp.

Townsend, C.F. 1960: Memorandum on subsidence problems at the Minadar Mine, Stirling, Richmond County, Nova Scotia. Nova Scotia Department of Mines and Energy, Open File Report 566.

Tyler, D.A and Ladd, J.W. 1980: Vertical crustal movement in Maine. Maine Geological Survey, Open File Report 80-34, 53 pp.

Tyler, D.A. and Leick, A. 1985: St. Croix region crustal strain study. Maine Geological Survey, Open File Report 85-76, 22 pp.

Tyler, D.A., Ladd, J. and Borns, H.W. 1979: Crustal subsidence in eastern Maine. Maine Geological Survey, Open File Report 79-24, 11 pp.

Uchupi, E. and Austin, J.A. 1979: Stratigraphy and structure of the Laurentian Cone region. Canadian Journal of Earth Sciences, 16, 1726-1752.

Vaniček, P. 1975: Vertical crustal movements in Nova Scotia as determined from scattered geodetic relevellings. Tectonophysics, 29, 183-189.

Vaniček, P. 1976: Pattern of recent vertical crustal movements in Maritime Canada. Canadian Journal of Earth Sciences, 13, 661-667.

Vaniček, P. and Nagy, D. 1981: On the compilation of the map of contemporary vertical crustal movements in Canada. Tectonophysics, 71, 75-86.

Wade, J.A. 1981: Geology of the Canadian Atlantic margin from Georges Bank to the Grand Banks. in Geology of the North Atlantic Borderlands, ed. W. Kerr and A. Ferguson, Canadian Society of Petroleum Geology, Memoir 7, 447-460.

Wait, J.H. 1959: Geology of the Mabou area, Cape Breton Island, Nova Scotia, Canada. Unpublished B.Sc. thesis, Bates College, Lewiston, Maine.

Wang, S.-C., Stein, S., Sleep, N.H. and Geller, R.J. 1979: Earthquakes along the passive margin of eastern North America induced by glaciation. EOS, 60 (18), 310.

Webb, G.W. 1973: Salt structures east of Nova Scotia. 197-218 in Earth Science Symposium on Offshore Eastern Canada, ed. P.J. Hood, Geological Survey of Canada, Paper 71-23.

Weeks, L.J. 1948: Londonderry and Bass River map-areas, Colchester and Hants counties. Geological Survey of Canada, Memoir 245.

Weeks, L.J. 1954: Southeast Cape Breton Island. Geological Survey of Canada, Memoir 277.

Weichert, Dieter H. 1985: New Brunswick strong ground motion records. Physics of the Earth and Planetary Interiors, 38 (2-3), 83-91.

Westerman, D.S. 1983. Structural analysis of the Guilford, Dover-Foxcroft, and Boyd Lake 15-Minute quadrangles, south-central Maine. Maine Geological Survey, Open File Report 83-7, 22 pp.

Weston Geophysical Corporation. 1983: Seismological and geological studies, Miramichi area, New Brunswick and central New Hampshire, Volume I. Prepared for Maine Yankee Atomic Power Company, Public Service Company of New Hampshire, Vermont Nuclear Power Corporation and Yankee Atomic Electric Company, August 1983.

Weston Geophysical Corporation. 1984: Geological & seismological studies, Millstone nuclear power station - unit 3, response to NRC information requests Q230.4, Q230.6 and Q230.7, Volume I. Prepared for Northeast Utilities Service Company, April 1984. 35 pp.

Wetmiller, R.J., Adams, J., Anglin, F.M., Hasegawa, H.S. and Stevens, A.E. 1984: Aftershock sequences of the 1982 Miramichi, New Brunswick, earthquakes. Bulletin of the Seismological Society of America, 74 (2), 621-653.

White, P.L. 1987: Local subsidence on N.B. route 860, the Salt Springs road. Unpublished senior undergraduate thesis, No. TGE-21, Department of Geological Engineering, University of New Brunswick, Fredericton, New Brunswick.

Wightman, D.M. 1980: Late Pleistocene glaciofluvial and glaciomarine sediments on the north side of the Minas Basin, Nova Scotia. Unpublished Ph.D. thesis, Dalhousie University, Halifax, Nova Scotia.

Wightman, D. and Cooke, H.B.S. 1978: Postglacial emergence in Atlantic Canada. Geoscience Canada, 5, 61-65.

Wright, W.J. 1950. The Lancaster landslide. Department of Lands and Mines, Mines Branch, Paper 49-3, 109 pp.

ACKNOWLEDGEMENTS

The author is particularly grateful for the assistance of, and encouragement provided by, the following individuals: J. Adams, Earth Physics Branch, Geological Survey of Canada; and J.L. Wallach, Atomic Energy Control Board. Valuable help also was received from K.B.S. Burke, Geology Department, University of New Brunswick; A.A. Ruitenberg and D.J.J. Carroll, New Brunswick Department of Natural Resources; R.Stea and D. Keppie, Nova Scotia Department of Mines and Energy; and A. Ruffman, Geomarine Associates Ltd.

APPENDIX A: SELECTED UNANNOTATED REFERENCES CONCERNING THE 1982 MIRAMICHI EARTHQUAKES AND RELATED AFTERSHOCKS

The 9 January 1982 earthquake centred in the Miramichi area of northern New Brunswick created thousands of micro- and several macro-aftershocks. It also triggered a (not quite equal) number of articles, papers, reports, abstracts and unpublished speculations as to its source, effects and other parameters. Perhaps the most salient of the many titles to appear was the one by Basham et al. (1984): Miramichi Earthquakes Two Years Later - What Have We Learned?

The following pages cite by no means all unannotated articles on the earthquake and its aftershocks. They do, however, provide a partial reading list for persons interested in further research on the Miramichi seismic events.

Miramichi Earthquake References

Adams, J. and Wetmiller, R.J. 1984: The Miramichi earthquake sequence of 1982-1984 and its relation to regional crustal stresses in New Brunswick. Abstract in Joint Programme with Abstracts, 18th Annual Congress, Canadian Meteorological and Oceanographic Society, Dalhousie University, Halifax, Nova Scotia, 29 May-1 June 1984.

Boatwright, J. and Astrue, M. 1983: Stress drops of the aftershocks of the 1982 New Brunswick earthquake. Earthquake Notes, 54 (1), 6.

Buchbinder, G.G.R., Wetmiller, R.J., Stevens, A.E., Hasegawa, H.S. and Adams, J. 1982: The Miramichi, New Brunswick earthquake sequence of January, 1982. EOS, 63 (18), 382-383.

Burke, K.B.S. and Chandra, J.J. 1983: Preliminary interpretation of gravity and magnetic results from the epicentral region of the 1982 Miramichi earthquakes. Abstract in Atlantic Geoscience Society Symposium, January 28-29, 1983, Fredericton, New Brunswick.

Burke, K.B.S. and Chandra, J.J. 1983: Gravity survey of the epicentral area of the main sequence of 1982 Miramichi earthquakes. New Brunswick Department of Mines and Energy, Mineral Resources Division, Open File Report 83-3, 21 pp.

Chael, E.P. 1987: Spectral scaling of earthquakes in the Miramichi region of New Brunswick. Bulletin of the Seismological Society of America, 77 (2), 347-365.

Choy, G.L., Boatwright, J., Dewey, J.W. and Sipkin, S.A. 1983: A teleseismic analysis of the New Brunswick earthquake of January 9, 1982. Journal of Geophysical Research, 88 (B3), 2199-2212.

Choy, G.L., Dewey, J.W., Needham, R.E., Sipkin, S.A. amd Zirbes, M.D. 1982: Teleseismic studies of the central New Brunswick earthquake of 9 January 1982. Earthquake Notes, 53 (1), 18.

Cranswick E. 1984: Stress-drop of aftershocks of the Miramichi earthquake recorded in July 1983. EOS, 65 (16), 240.

Cranswick, E. and Mueller, C. 1982: Source parameters of aftershocks of the January 9, 1982 New Brunswick earthquake. EOS, 63 (18), 383.

Cranswick, E., Wetmiller, R. and Boatwright, J. 1985: High-frequency observations and source parameters of microearthquakes recorded at hard-rock sites. Bulletin of the Seismological Society of America, 75 (6), 1535-1567.

Diment, W.H., Stover, C.W. and Kane, M.F. 1982: The central New Brunswick earthquake sequence of 1982: history, distribution of intensity and tectonic environment. Earthquake Notes, 53 (1), 17.

Hasegawa, H.S. 1983: Surface wave analysis of the magnitude 5.7 Miramichi, New Brunswick, earthquake of 09 January 1982. Earthquake Notes, 54 (1), 84.

Hasegawa, H.S. 1986: Seismotectonics in eastern Canada: an overview with emphasis on the Charlevoix and Miramichi regions. Earthquake Notes, 57 (3), 83-94.

Hasegawa, H.S., Adams, J., Wetmiller, R.J. and Basham, P.W. 1982: The seismotectonic setting of the New Brunswick, Canada, earthquakes of January - April 1982: EOS, 63 (51), 1249.

Mueller, C.S. and Cranswick, E. 1984: Source parameters from locally-recorded aftershocks of the Jan. 9, 1982, Miramichi earthquake. Earthquake Notes, 55 (3), 9.

Pulli, J.J. and Toksoz, M.N. 1982: Source mechanisms of recent moderate earthquakes in the northeastern US - implications for the state of stress in the crust. EOS, 63 (18), 382.

Saikia, C.K. 1984: Modelling of direct P- and S-phases of 3-local earthquakes of New Brunswick area, Canada. EOS, 65 (16), 240.

Saikia, C.K. and Herrmann, R.B. 1984: Source mechanism and characteristics of the aftershocks of the New Brunswick earthquake, 1982. Earthquake Notes, 55 (3), 10.

Stevens, A.E. 1983: Intensity studies of some 1982 Miramichi, New Brunswick, Canada, earthquakes. EOS, 64 (18), 266-267.

Weichert, D.H. 1982: Strong motion recordings from New Brunswick 1982 aftershocks. Earthquake Notes, 53 (3), 40.

Weichert, D.H. 1983: Was Miramichi-1982 a typical eastern Canadian earthquake? Earthquake Notes, 54 (1), 6.

Wetmiller, R.J. 1984: Long term aftershock activity in the Miramichi, New Brunswick aftershock zone. Earthquake Notes, 55 (3), 9.

Wetmiller, H.S., Adams, J., Stevens, A.E., Anglin, F.M. Hasegawa, H.S. and Berube, J. 1982: Aftershock sequences for the New Brunswick earthquakes of January 9th and 11th, March 31st and June 16th, 1982. Earthquake Notes, 53 (3), 41.

APPENDIX B: SELECTED REFERENCES DESCRIBING POST TRIASSIC BEDROCK FAULTING OF INDETERMINATE UPPER AGE

The following references describe post-Triassic faulting for which the upper age has not yet been clearly determined.

New Brunswick

Adams (unpublished report)

An outcrop in the Miramichi earthquake epicentre shows horst and graben type deformation. Nine blocks, each 3 m wide, are alternately upthrown and downthrown on the order of approximately 100 mm. At the east end of the outcrop, evidence suggests a much larger displacement of perhaps 600 mm.

Greiner 1965

The Bonaventure Formation occurs in the Charlo map area on the south shore of Chaleur Bay. It is lithologically similar to Triassic redbeds in the Bay of Fundy, and is tentatively assigned a post-Triassic and perhaps Cretaceous age. Rocks of the Bonaventure Formation have been sheared in an area west of Parent Point.

Greiner later (1970) describes a silicified limestone breccia that contains fragments possibly derived from the Bonaventure Formation. The breccia was found along a railway line 400 feet west of the road leading to Parent Point, suggesting it may be the outcrop referred to above.

The Bonaventure Formation thus could pre-date the latest structural movements in the region. If so, and if the formation is indeed Cretaceous, then the latest deformation is also of that age.

MacKenzie 1940

"Some faults are to be discerned along the shores of Oak Bay and a major fault underlies the bay. These are of post-Devonian, and possibly of Mesozoic or even younger age..." (p. 24). No clear substantiation is given for this cryptic statement.

Ruitenberg 1970

Rocks in the Black River area, southern New Brunswick, have been affected by small east-northeasterly trending faults. The faults appear to be the latest structures in the area, and in most instances dip steeply. Slickensides on hematite coatings, and small drag folds associated with the faults, indicate that normal movement took place sometime after the hematite was deposited.

Nova Scotia

Dickie 1986

Tectonic block faulting occurred in the vicinity of the Musquodoboit and Shubenacadie valleys, as evidenced by the remnant Cretaceous sand and clay deposits preserved in those areas. Block faulting is believed to be Albian (mid-Cretaceous) in age.

Donohoe and Wallace 1979a

North-south trending faults in the Cobequid Highlands offset all other faults and the Early Jurassic Fundy Group strata. Movement is therefore thought to be post-Early Jurassic. Examination of the detailed 1:50,000 maps suggests that the north-south trending faults have had several episodes of movement (Donohoe and Wallace 1980).

Donohoe and Wallace 1979b

Faults parallel to the Cobequid Fault displace Late Triassic-Early Jurassic basalt by 3 km of right lateral displacement. Burton (1973) speculates that displacement on the Cobequid Fault itself included Triassic dextral movement, and post-Triassic transform movement.

Doyle 1979

A post-Triassic fault trending northeast occurs at Thorn Cove on North Mountain, 9 km north of the mouth of Bear River. Many faults in the Bear River area have similar trends, indicating that they also might be post-Triassic.

Hwang 1985

High angle, north-northeast trending faults occur in lower Paleozoic rocks of the Meguma Group and White Rock Formation near Yarmouth. These rocks are also affected by post-Acadian dextral kink band deformation. The high angle faults displace the kink banding, and are very tentatively suggested as being Cretaceous.

Lollis 1959

Repetitive faults along the Bay of Fundy coast between Digby Neck and Scots Bay cut and offset Early Jurassic rocks of the Scots Bay Formation (see also Thompson 1974, Liew 1976 and Stevens 1987.)

The fault zone running through Petit Passage is of particular interest. Cables formerly linking Boar's Head lighthouse with Digby Neck apparently required periodic replacement. Wires lying over the fault zone in the centre of the passage tended to become green and corroded after (only a few years) underwater.
being

Weeks 1948

Five faults believed to be post-Triassic have been located in the Londonderry-Bass River map areas on the north side of the Minas Basin. Only one continues south of Cobequid Bay. All trend north-south and are downthrown on the east side.

Weeks 1954

Block faulting of Carboniferous rocks in southeast Cape Breton Island occurred sometime before formation of the Cretaceous peneplain. It also occurred after deposition of the (probable) Middle to Upper Triassic Annapolis Formation. This places the block faulting at sometime between the Late Triassic and Cretaceous.

APPENDIX C: A READING LIST TO AID IN DISTINGUISHING NEOTECTONIC FEATURES IN THE FIELD

Neotectonic features are often overlooked in the field. This is partly because they are not anticipated. Neotectonism is as new a concept as it is geologically recent, and is only just beginning to acquire a small following of specialists. They, more than most geologists, must be well versed in a variety of earth sciences. Geomorphology, structural geology and geodesy are not commonly assembled in one person. Yet a working knowledge of these and other sub-disciplines must be mastered by the would-be neotectonist.

The other reason for field neglect of neotectonic features is that they so often resemble non-neotectonic features. The reading list below will begin to help geologists distinguish the two. It is not complete, nor foolproof. At best, the references show reason to pause before automatically slotting a given field observation into non-neotectonic structural or geomorphological categories.

Neotectonics Reading List

Adams, J. 1981: Postglacial faulting: a literature survey of occurrences in eastern Canada and comparable glaciated areas. Atomic Energy of Canada Ltd., Technical Record, TR-142, 63 pp.

Adams, J. 1982a: Deformed lake sediments record prehistoric earthquakes during the deglaciation of the Canadian Shield. EOS, 63 (17), 436.

Adams, J. 1982b: Stress-relief buckles in the McFarland quarry, Ottawa. Canadian Journal of Earth Sciences, 19 (10), 1183-1187.

Alexander, S.S. 1978: Combined use of seismic and remote sensing observations to relate present crustal stresses and geologically recent deformation. EOS, 59 (4), 330.

Allen, C.R. 1978: Quaternary geology - an essential clue to evaluating seismicity. Earthquake Information Bulletin, 10 (1), 4-12.

Barosh, P.J. and Smith, P.V. 1979: Frostquakes and associated ground breakage in New England. Earthquake Notes, 5 (3), 12.

Beck, B.F. and Jenkins, D.T. 1985: Damage caused by long-term, gradual karstic subsidence. Abstracts with Programs, Geological Society of America, 17, 521.

Broster, B.E. and Clague, J.J. 1987: Advance and retreat glacigenic deformation at Williams Lake, British Columbia. Canadian Journal of Earth Sciences, 24, 1421-1430.

Croot, D.G. 1987: Glacio-tectonic structures: a mesoscale model of thin-skinned thrust sheets? Journal of Structural Geology, 9 (7), 797-808.

Doig, R. 1986: A method for determining the frequency of large-magnitude earthquakes using lake sediments. Canadian Journal of Earth Sciences, 23, 930-937.

Doornkamp, J.C. 1986: Geomorphological approaches to the study of neotectonics. Journal of the Geological Society, London, 143, 335-342.

Gendzwill, D.J., Horner, R.B. and Hasegawa, H.S. 1982: Induced earthquakes at a potash mine near Saskatoon, Canada. Canadian Journal of Earth Sciences, 19, 466-475.

Hempton, M.R. and Dewey, J.F. 1983: Earthquake-induced deformational structures in young lacustrine sediments, East Anatolian Fault, southeast Turkey. Tectonophysics, 98, T7-T14.

Hicock, S.R. and Dreimanis, A. 1985: Glaciotectonic structures as useful ice-movement indicators in glacial deposits: four Canadian case studies. Canadian Journal of Earth Sciences, 22, 339-346.

Keefer, D.K. 1982: Relations between earthquake magnitude, levels of shaking, and landslides. Geological Society of America, Abstracts with Programs, 14, 526.

Keefer, D.K. 1984: Landslides caused by earthquakes. Geological Society of America Bulletin, 95, 406-421.

McDonald, B.C. and Shilts, W.W. 1975: Interpretation of faults in glaciofluvial sediments. p. 123-131 in Society of Economic Paleontologists and Mineralogists, special publication no. 23 (Glaciofluvial and glaciolacustrine sedimentation).

Obermeier, S.F., Gohn, G.S. and Weems, R.E. 1984: Geologic evidence for prehistoric earthquake-induced liquifaction and ground deformation near Charleston, South Carolina. Earthquake Notes, 55 (3), 6.

Obermeier, S.F., Jacobson, S.F. Weems, R.E. and Gohn, G.S. 1986: Holocene and Late Pleistocene (?) earthquake-induced sandblows in coastal South Carolina. Earthquake Notes, 57 (1), 17.

Oliver, J., Johnson, T. and Dorman, J. 1970: Postglacial faulting and seismicity in New York and Quebec. Canadian Journal of Earth Sciences, 7, 577-590.

Saxov, S. and Nieuwenhuis, J.K., ed. 1980: Marine slides and other mass movements. Proceedings of a NATO workshop on marine slides and other mass movements, Algarve, Portugal, December 15-21, 1980. NATO Conference Series, part IV, volume 6, Plenum Press, New York, 353 pp.

Seeber, L., Thorson, R.M. and Clayton, W. 1985: Liquifaction and clastic injection in postglacial sediments of eastern Connecticut: evidence for large prehistoric earthquakes? Earthquake Notes, 56 (3), 70.

Shilts, W.W. 1984: Sonar evidence for postglacial tectonic instability of the Canadian Shield and Appalachians. Geological Survey of Canada, Paper 84-1A, 567-579.

Sims, J. 1979: Records of prehistoric earthquakes in sedimentary deposits in lakes. Earthquake Information Bulletin, 11 (6), 228-233.

Sims, J.D. 1982: Earthquake-induced deformation in sediment as a paleoseismic indicator. EOS, 63 (18), 435.

Stow, D.A.V. and Aksu, A.E. 1978: Disturbances in soft sediments due to piston coring. Marine Geology, 28, 135-144.

Wyss, M. 1978: Sea-level changes before large earthquakes. Earthquake Information Bulletin, 10 (5), 165-168.

APPENDIX D - CONTACT ADDRESSES FOR REFERENCES CITED AS PERS. COMM. OR UNPUBLISHED

John Adams:
Earth Physics Branch
Department of Energy, Mines and Resources
Ottawa, Ontario

Carl Amos:
Atlantic Geoscience Centre
Bedford, Nova Scotia

Robert Boehner:
Nova Scotia Department of Mines and Energy
Halifax, Nova Scotia

John Calder
Nova Scotia Department of Mines and Energy
Halifax, Nova Scotia

Les Fyffe	New Brunswick Department of Natural Resources and Energy Fredericton, New Brunswick
John Gilby:	Golder Associates Mississauga, Ontario
Douglas Grant:	Geological Survey of Canada Department of Energy, Mines and Resources Ottawa, Ontario
Donaldson Koons:	is retired, but can be reached through Department of Geology Colby College Waterville, Maine
Michel Lamothe:	Geological Survey of Canada Department of Energy, Mines and Resources Ottawa, Ontario
Michal Lodin:	Department of Surveying Engineering University of New Brunswick Fredericton, New Brunswick
Steve McCutcheon:	New Brunswick Department of Natural Resources and Energy Bathurst, New Brunswick
Miquel Pedroza:	Department of Surveying Engineering University of New Brunswick Fredericton, New Brunswick
Martin Rappol	c/o W.W. Shilts Geological Survey of Canada Department of Energy, Mines and Resources Ottawa, Ontario
Alan Ruffman:	Geomarine Associates Ltd. Halifax, Nova Scotia
Ralph Stea	Nova Scotia Department of Mines and Energy Halifax, Nova Scotia
C. Van Staal	Geological Survey of Canada Department of Energy, Mines and Resources Ottawa, Ontario
P. Vaníček	Department of Surveying Engineering University of New Brunswick Fredericton, New Brunswick